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40 KILOWATT FUEL CELL POWER PLANTS FOR THE McCLELLAN AIR FORCE BASE RADAR APPROACH CONTROL (RAPCON) FACILITY

Energy Conversion Branch
Aerospace Power Division (POOC)

June 1983

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AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This study evaluated the McClellan Air Force Base Radar Approach Control Facility as a site to operationally field test two 40 kW fuel cells and developed concepts from which detailed installation specifications and field construction activities can be made.

The study presents several alternative means of utilizing the fuel cells' electrical and thermal output and compares the various alternatives against installation cost, operating cost, reliability, and total energy utilization.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) cont A site utility system description is presented along with an explanation of the fuel cell plant. Several fuel cell modifications are also suggested and site instrumentation requirements are summarized.

The study finds the McClellan facility to be an acceptable site for fuel cell testing. Although utility costs will increase in the facility if the cells are installed (low cost hydro-electric power vs. higher priced natural gas produced electrical power), these costs are outweighed by other factors such as minimal facility modification costs, site environmental conditions, and availability of maintenance forces.

FOREWORD

This report was prepared for the Aerospace Power Division, Aero Propulsion Laboratory, Wright-Patterson AFB (AFWAL/POO), by the Aeronautical Systems Division (ASD/XOR) Air Force Reserve Houston Detachment. The report summarizes a study which began in March 1980. The objective of this study was threefold: 1) evaluate the McClellan Air Force Base Radar Approach Control (RAPCON) facility as a potential site to operationally field test two 40-kW fuel cells; 2) investigate alternate methods to integrate the fuel cells into that facility; and 3) determine the most expeditious method to implement installation of the fuel cells.

In gathering information for this study, members of the Houston Reserve Detachment visited McClellan AFB to discuss operational constraints with the FAA personnel in charge of the RAPCON facility. Details of the building systems were reviewed with representatives from the McClellan Civil Engineering office and the existing utility system was checked against available facility drawings. Houston Reserve Detachment representatives also traveled to the United Technologies Corporation (UTC) Power System Division manufacturing facility in Hartford, Connecticut, to receive detailed briefings on the design, manufacture, and operation of the 40-kW fuel cells.

This report was submitted by the Aero Propulsion Laboratory, under project/task/work unit 31452422 with First Lieutenant Richard G. Honneywell as project engineer.

The Houston ASD Reserve Detachment wishes to express its appreciation to the personnel of the Sacramento Air Logistics Center, United Technologies Power Systems Division, and Air Force Wright Aeronautical Laboratory for their assistance in this study.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

In recent years the concept of fuel cell power plants has received considerable attention as a new option for providing the thermal and electrical energy requirements of residential, commercial, and industrial buildings. Fuel cells are efficient energy conversion devices and are typically located in or near the facility being supplied power. As a result, large electrical transmission losses are eliminated and the heat produced in the power generation process can be used to meet the thermal needs of the facility. In addition, environmental pollution problems associated with fuel cell usage are minimal.

The purpose of this study is to evaluate the McClellan Air Force Base Radar Approach Control (RAPCON) Facility as a site to operationally field test two 40kW fuel cells and to develop concepts from which detailed installation specifications and field construction plans can be generated.

The study presents several alternative means of utilizing fuel cell electrical and thermal output and compares the various alternatives against installation cost, operating cost, reliability, and total energy utilization. A site utility system description is presented along with an explanation of the fuel cell plant. Several fuel cell modifications are also suggested and site instrumentation requirements are summarized.

The study finds the McClellan facility to be an acceptable site for fuel cell testing. Although utility costs will increase in the facility if the cells are installed (low cost hydro-electric power vs. higher priced natural gas produced electrical power), these costs are outweighed by other factors such as minimal facility modification costs, site environmental conditions, and availability of skilled maintenance personnel.

SECTION I

INTRODUCTION

Considerable effort has been made in recent years to produce electrical energy more efficiently. This effort has been accelerated by the acknowledgement of the limited reserves of fossil fuels, especially natural gas and oil. In addition to efficiency, environmental impact, reliability, life cycle costs, and fuel availability are also important when considering alternative energy generation techniques.

The fuel cell is one high efficiency generation system under consideration by the Department of Energy (DOE) which appears to satisfy the above requirements. DOE estimates that in the near term fuel cell technology could save this nation 270,000 barrels of oil equivalents per day, which corresponds to approximately one billion dollars in foreign imports per year (Reference 1). While the principles of the fuel cell have been known since 1801, it was only in recent years that commercially practical units have developed.

In 1974, a pilot 40-kW fuel cell on-site power plant was designed and fabricated by the Power Systems Division of United Technologies Corporation (UTC). This power plant was tested, and found to have many of the operating characteristics required for commercial service. As a result of these successful preliminary tests, the national Fuel Cell Operational Feasibility Program was conceived. This program proposed to evaluate a number of the 40kW units in operational environments.

Participants in this program (natural gas and electrical utility companies, the Gas Research Institute, and Department of Defense) are currently evaluating potential sites which can be used in a one-year test program scheduled to start in FY83.

Coordination of the Air Force portion of the DOD effort has been assigned to the Air Force Wright Aeronautical Laboratories, Aerospace Division (AFWAL/POOC) Wright-Patterson AFB, OH. AFWAL/POOC will manage the installation and operation of two 40-kW fuel cells at selected Air Force installations. During the site selection phase of this project, AFWAL/POOC requested that the Aeronautical Systems Division Reserve Program Office (ASD/XOR) prepare an evaluation of one potential fuel cell installation site.

This report is prepared by a group of ASD/XOR Reserve Officers and evaluates the RAPCON Facility at McClellan Air Force Base as a potential site for fuel cell installation. The report evaluates the feasibility of using two 40-kW fuel cells to provide the electrical and thermal requirements of the RAPCON facility and determines if fuel cell use would be advisable from a cost, efficiency, and reliability standpoint. The report contains descriptions of the fuel cells and proposed site. The facility requirements for electrical and thermal energy are compared against fuel cell outputs and operating costs of the cells are compared against purchased power costs. Several fuel cell installation concepts are presented. Each concept is evaluated against installation costs, operating costs, reliability, and total facility energy usage. Several fuel cell modifications are also suggested. Two approaches for developing detailed design specifications are presented as well as suggestions for implementing the construction phase of the project.

SECTION II

TEST SITE DESCRIPTION

1. STRUCTURE

The test site under consideration for the on-site fuel cell demonstration project is Building 1099 located at McClellan Air Force Base. The building is located in a remote area of the base with easy access by several roads. This two story concrete, masonry structure was constructed in 1962, and enlarged in 1972. Modifications were incorporated in 1975 and 1977.

The building contains approximately 13,000 square feet of floor space and is used as a Federal Aviation Administration Radar Approach Control Station (RAPCON). The building contains computers, radar display consoles, communication equipment, maintenance shops, office space, and mechanical equipment rooms containing heating-ventilation-air conditioning (HVAC) systems and emergency power generation equipment. The equipment rooms are located at one end of the building on the lower level with easy outside access.

2. CLIMATE

The test site is located near Sacramento, California in an area of moderate climatic conditions. Temperatures are generally mild with no extreme seasonal variations. Humidity levels are low and the area is characteristically one of low winds, low rainfall and no snow.

3. UTILITIES

The Sacramento Utility District supplies natural gas and electrical power for all the building's energy requirements except emergency back-up electrical power which is furnished by a diesel-driven electrical generator.

The quantities of electrical power and natural gas consumed during ten consecutive months of building operation in 1979 are shown in Table 1. The second column of this table shows the amount of gas (in therms) delivered to the boilers during each month of the period. The third column is based on boiler efficiency and shows the heat actually delivered

TABLE 1

McCLELLAN AFB RAPCON FACILITY UTILITY USAGE

MONTH -1979-	INPUT (THERMS)	AVERAGE OUTPUT HEAT RATE -80% EFF (BTU/HR)	FUEL COSTS (DOLLARS)	ELECTRICAL INPUT (KWH)	PEAK DEMAND (KW)	ELECTRICAL COST (DOLLARS)	COMBINED UTILITIES COST (DOLLARS)
JAN	3153	339,036	1362	62 520	112	1188	2550
FEB	3266	388,810	1411	68 520	106	1302	2713
MAR	1825	196,238	788	61 200	112	1163	1951
APR	1766	196,224	763	60 840	106	1156	1919
MAY	1304	140,217	563	62 400	117	1186	1749
JUN	989	109,895	427	72 120	120	1370	1797
JUL	551	59,248	238	67 560	121	1284	1522
AUG	678	72,904	293	64 920	122	1233	1526
SEP	1033	114,778	446	72 840	122	1384	1830
OCT	1529	164,410	661	63 960	122	1215	1876

to the building through the HVAC system. The corresponding costs of electrical power and natural gas are also shown.

4. ELECTRICAL SYSTEM

The facility's electrical requirements are supplied by the Sacramento Utility District's 12,000-volt service. This service is connected to the primary side of the facility's 225-kVA transformer, with the secondary side of the transformer (120/208 volt, 3Ø, 60 Hz) connected to the building's main switchboard through an 800 amp circuit breaker. A three-phase, four-conductor system is used throughout the main switchboard.

Two buses are connected to the building side of the 800-amp circuit breaker. The "normal" bus is rated at 800 amps and the "emergency" bus is rated at 600 amps. Under normal conditions, the "emergency" bus is connected to the incoming service through an automatic transfer switch. In the event commercial power is lost, the transfer switch is automatically repositioned and supplies power to the "emergency" bus from the back-up power system. The "normal" bus is not supplied by the emergency power system during loss of commercial power.

Low-voltage sensing circuits detect loss of commercial power and automatically start the emergency diesel generator by means of storage batteries. Timer circuits trip the automatic transfer switch when the generator has reached operating speed and can carry the load. This transfer takes place within a few seconds after loss of commercial power.

A schematic of the facility's electrical power distribution system is shown in Figure 1.

5. HVAC MECHANICAL SYSTEM

Building humidity and temperature are maintained by a conventional forced-air circulation system. Major components of this system include air handlers and associated distribution ducting, hot water boilers, water chillers, and integrating controls. The system uses a hot water/chilled water system to dehumidify air by cooling and then reheating the air to maintain the temperature required in various areas of the facility.

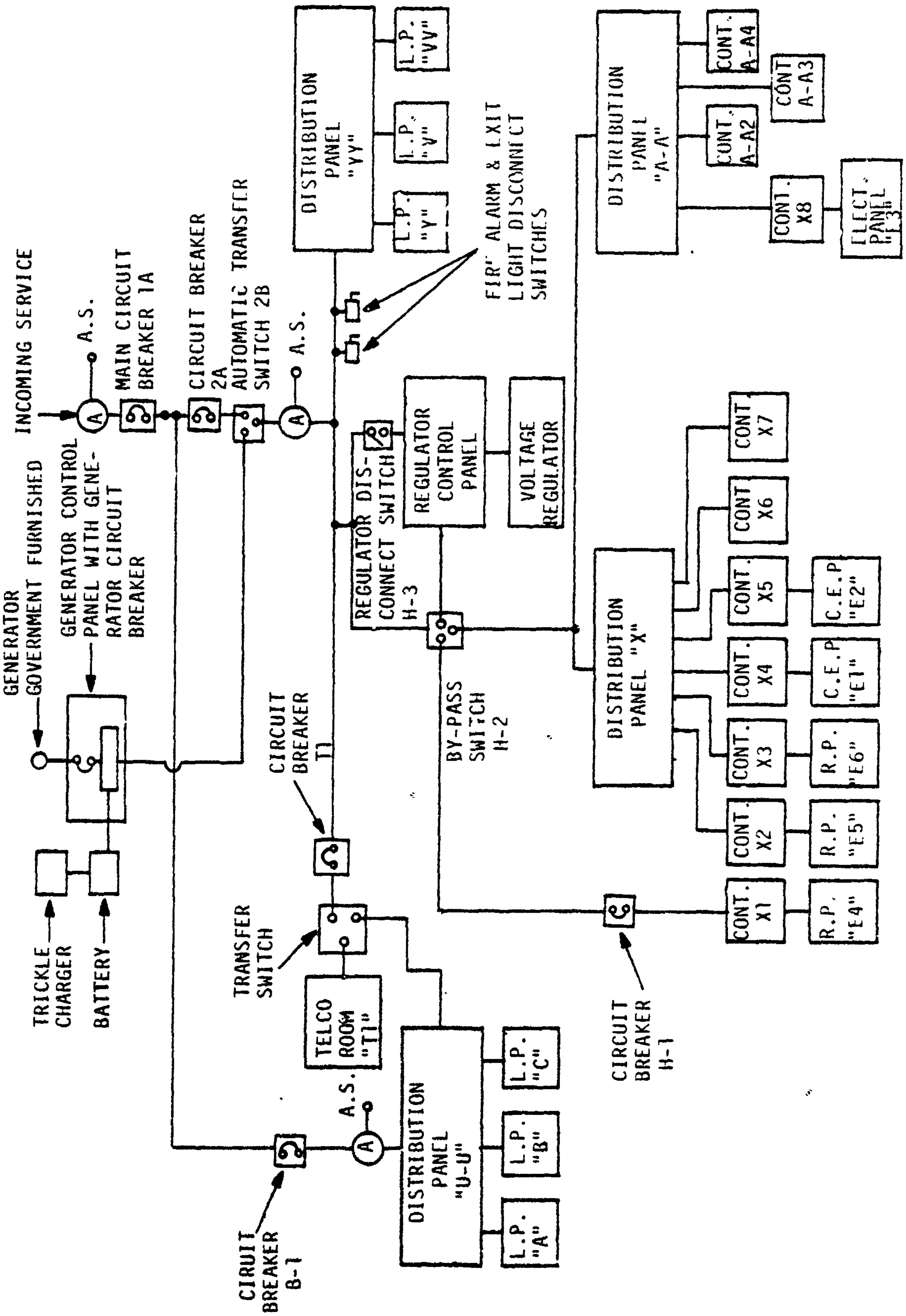


Figure 1. McClellan AFB RAPCON Facility Electrical Power Distribution Schematic

a. Air Conditioning/Distribution System

The air conditioning/distribution system consists of four air handlers with associated distribution and return air ducting. Two unit heaters, and one finned-tube radiator are also included in the system. The air handlers are equipped with both hot and chilled-water coils, while the two unit heaters and the finned-tube radiator are equipped with only hot-water coils. The air handlers are installed in various locations in the building. Air handlers AC-1 and AC-2 are located in the equipment room, AC-3 is located above a suspended ceiling, and AC-4 is located on the roof. One of the unit heaters is located in the generator room and the other in the equipment room. The finned-tube radiator is located in one of the second floor restrooms. The air handlers are equipped with distribution, return, and fresh air intake ducts while the unit heaters and radiator are mounted in the area to be heated and are not equipped with air distribution ducts. Air handlers AC-1 and AC-3 provide conditioned air to single zones and AC-2 and AC-4 provide conditioned air to multiple zones in the building. Table 2 lists design specifications for each of the HVAC components.

Humidistats and thermostats automatically control the fresh air intake damper positions on the air handlers to minimize the heating and cooling loads. This control allows large quantities of outside air to be admitted into the building during moderate temperature/humidity periods, but restricts outside air intake during extreme temperature/humidity periods when large amounts of heating or cooling would be required.

b. Hot Water System

The HVAC hot water system is described in Figure 2. This system utilizes two natural gas boilers (one located in the equipment room, rated at 350,000 Btu/hr output and the other located in a temporary sheet metal structure adjacent to the equipment room rated at 672,000 Btu/hr output). Natural gas for the boilers is supplied by a Sacramento Utility District underground pipeline at 6.0 inches of water pressure and at rates up to 600 standard cu. ft./hr.

The two boilers are connected in series. If one boiler is unable to supply the required heat, the second boiler is used to increase

TABLE 2

TEST SITE FACILITY HVAC SYSTEM DESIGN SPECIFICATIONS

UNIT	HOT WATER COILS				CHILLED WATER COILS				AIR SIDE DATA						
	Temp In(°F)	Temp Out(°F)	Water Flow Rate (GPM)	Rating (Btu/hr)	Temp In(°F)	Temp Out(°F)	Water Flow Rate (GPM)	Rating (Btu/hr)	Temp In(°F)		Temp Out(°F)		Flow Rate (cu.ft./min.)	Static Pressure (in H_2O)	Velocity (ft./min.)
									HC	CC	HC	CC			
Air Handler AC-1 (located in Mechanical Room)	200	180	7.0	69,000	48	58	56	280,000	53	81	57	64	14,700	2.0	1,750
Air Handler AC-2 (located in Mechanical Room)	200	180	8.0	80,000	48	58	16.5	82,500	59	84	79	64	3,750	1.75	1,360
Air Handler AC-3 (located in Suspended Ceiling)	200	180	4.5	43,000	48	58	7.6	38,000	59	82	81	64	1,780	1.5	1,750
Air Handler AC-4 (located on Roof)	200	180	10.6	102,500	48	58	47.5	238,000	64.5	79	75	56	9,000	1.0	Not Specified
Unit Heater UH-1 (located in Mechanical Room)	200	180	1.0	10,500	--	--	--	--							
Unit Heater UH-2 (located in Generator Room)	200	180	1.3	13,250	--	--	--	--							
Radiator HR-1 (located in Restroom)	200	180	0.2	2,200	--	--	--	--							

H.C. - Heating Coil
C.C - Cooling Coil

Ref McClellan AFB Civil Engineering, Bldg 1099 System Drawings

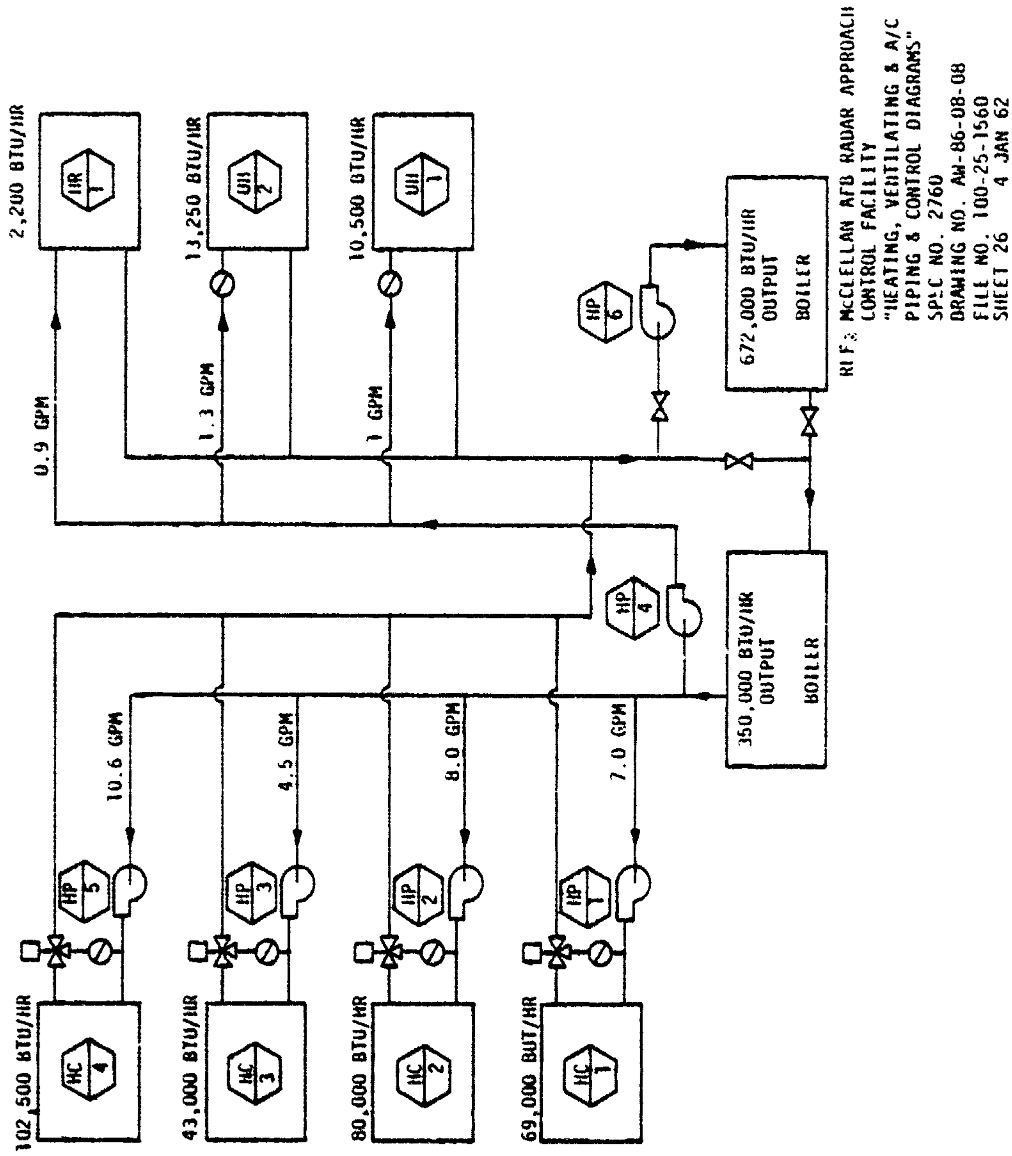


Figure 2. Block Diagram Test Site Hot Water System

the temperature of the water supplied by the first boiler. Thermostats control the boilers to maintain an outlet water temperature between 190°F and 200°F. Return water temperatures usually range from 150°F to 170°F.

In addition to the boilers, other major components included in the hot water system are six hot water circulation pumps, an expansion tank, pneumatic charge connection, a water make-up line, chemical additive tank, manually operated flow restriction valves, and pneumatically operated flow control valves.

Hot water is supplied to each of the four air handlers by an individual hot-water circulation pump. A separate circulation pump supplies hot water to the two unit heaters and the finned-tube radiator. The expansion tank, pneumatic charge connection, and water make-up line are used to control thermal expansion, system pressure, and water level in the hot-water system.

Manually operated flow restriction valves provide a means to adjust the water flow rates through the unit heaters and the finned-tube radiator. Pneumatically operated flow control valves automatically control the amount of hot water passing through each air handler heating coil as a function of the required heating load.

c. Chilled Water System

The chilled water system is described in Figure 3. Chilled water is supplied by three electric motor-driven, reciprocating compressor, chilled-water units. Two units are rated at 25 tons each and the third is rated at 23 tons. The two 25-ton units are located in the equipment room and employ water cooling towers to control condenser temperatures. The 23-ton unit is located outside of the building and uses an air-cooled condenser. All three units are connected in parallel and are sequentially started by a master controller depending on the facility cooling load. The master controller maintains the chilled water supply temperature at 48°F and the return water temperature at 58°F.

The system also contains expansion tanks, water make-up lines, pneumatic charge connections, chemical additive tanks, chilled water

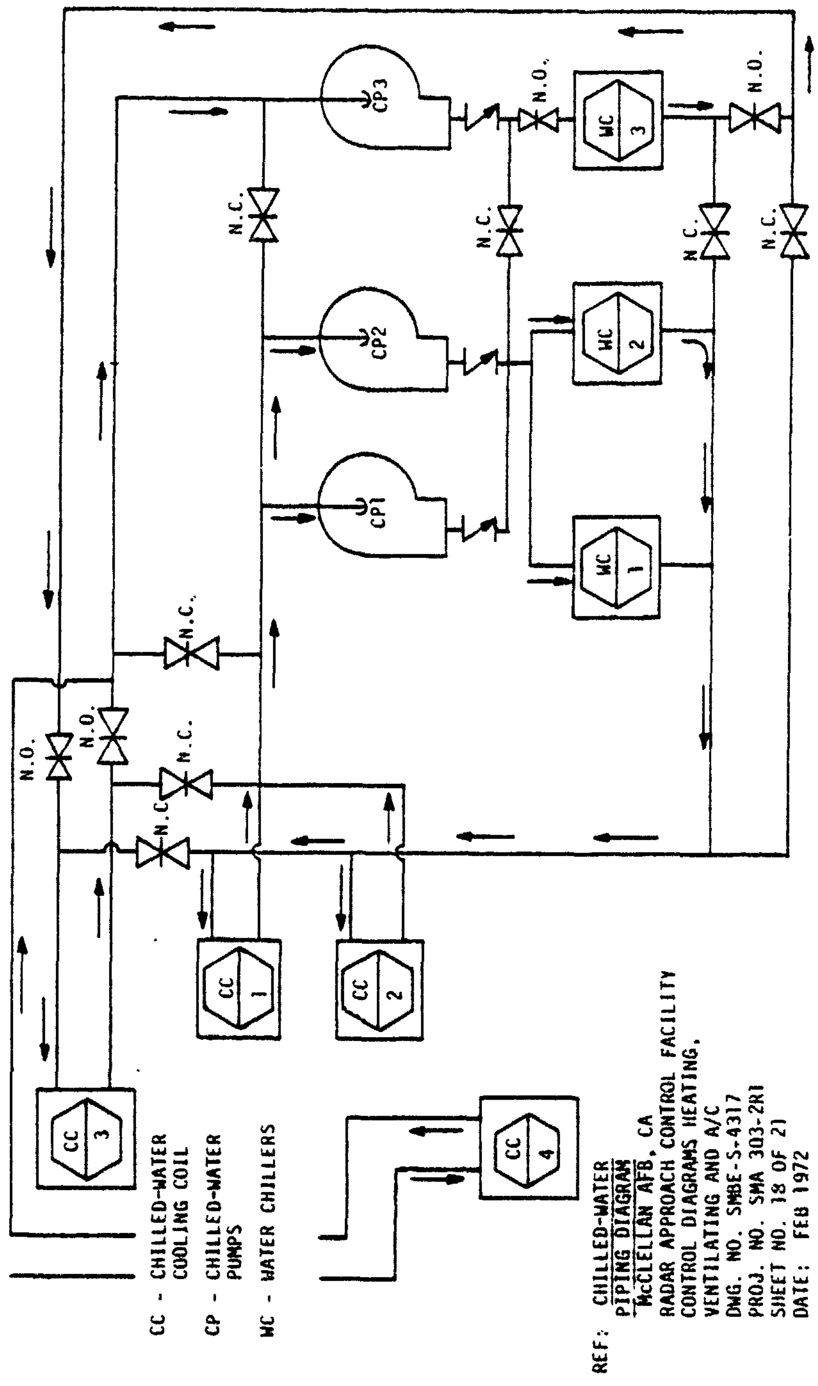


Figure 3. Block Diagram Test Site Chilled-Water System

circulating pumps, manually operated flow restriction valves, and pneumatically operated flow control valves.

6. HVAC CONTROL SYSTEM

The HVAC control system controls building temperature, humidity, and fresh air intake. This system uses a combination of thermostats, humidistats, temperature controllers, modulating dampers, pneumatically operated bypass valves, relays, contacts, load analyzer, etc. to maintain the required environmental conditions throughout the facility.

a. Unit Heaters and Radiator

Unit heaters UH-1 and UH-2 and radiator HR-1 are manually controlled. When heat is required in the generator room, equipment room, or supplemental heat is required in the upstairs restroom, the hot-water supply pump HP-4 is manually started. The hot-water flow rate to each unit is present by a manually adjustable restriction (balance) valve in each unit's return water line. Electric fans force air through the heating coils in the two unit heaters while natural convection provides air movement through the radiator.

b. Air Handler Units

Identical control systems regulate the quantity of fresh air supplied to the four air handlers and maintain system pressure within the facility. Two air handlers are single zone units and are controlled by thermostats located in their respective zones. The remaining two air handlers are multizone units. Both units are controlled by individual zone thermostats, however, one unit incorporates a load analyzer in the control loop. In all units, temperature of the return air to each air handler is regulated by a modulating duct thermostat. This thermostat is located downstream of the return air and fresh air intake duct connections, but upstream of the heating or cooling coils. This thermostat operates a damper position motor which controls the amount of fresh air admitted into the air handler. At low outside air temperatures, the dampers are positioned for minimum outside air intake and maximum return air flow to the heating coils. As outside air temperature rises, the thermostat gradually opens the outside-air damper and closes the return-air damper until only outside air is supplied to the coils. When outside air temperature reaches approximately 64°F, the outside-air damper is fully open and remains in this position until the outside air temperature rises to 80°F. At that temperature, a master two-position outside-air duct thermostat reverses the action of the modulating duct thermostat and begins to close the outside-air damper as the outside air temperature continues to rise.

A modulating duct humidistat overrides the modulating duct thermostat and closes the outside-air damper when the return air relative humidity rises above 50%.

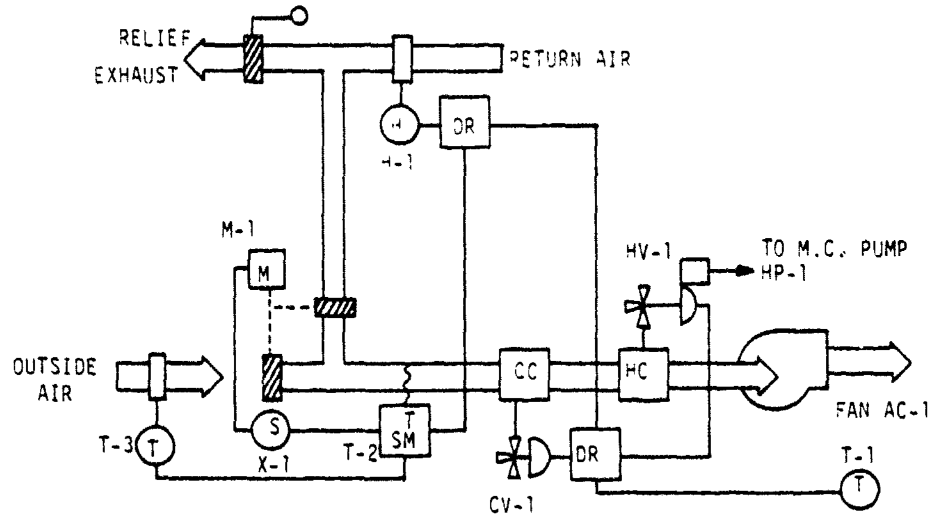
A manual damper select switch can be used to override the modulating duct thermostat. When set in the "normal" position, the modulating duct thermostat controls the damper positions if not overridden by the duct humidistat. When set in the "emergency" position, the outside air damper is returned to the minimum open position.

Positive air pressure within the facility is maintained at 0.1" of water by means of a relief exhaust damper.

Air handling units AC-1 and AC-3 are single-zone units. Output air temperature from each unit is controlled by a thermostat located in the zone served by the unit. This zone thermostat gradually opens the heating coil water valve as the room temperature falls below the set point and controls the cooling coil water valve through a diverting relay. The cooling coil water valve is also controlled by the humidistat. When the return air exceeds 50% relative humidity, the humidistat gradually opens the cooling coil water valve.

A switch mounted on the heating coil water valve stops the air handler hot-water circulating pump when the valve reaches the closed position (no heat input required). A similar switch is not provided on the cooling coil water valve since each chilled-water circulating pump provides chilled water to more than one air handler. Schematics describing the operation of AC-1 and AC-3 are provided in Figures 4 and 5.

Air handing unit AC-2 is a multi-zone unit that provides conditioned air to three zones in the building. Delivered air temperature to each zone is controlled independently by individual zone thermostats. A submaster modulating duct thermostat maintains the hot deck temperature



AIR CONDITIONING UNIT AC-1 CONTROL
McClellan AFB, CA.
Radar Approach Control Facility

Control System for Air conditioning Unit AC-1:

(A) Mixed air temperature is controlled by modulating duct thermostat T-2 which, at winter design temperature, operates damper motor M-1, for minimum outside air and maximum return air. As outside air temperature rises, T-2 gradually opens the outside air damper and closes the return air damper until the outside air damper is wide open when the set point (approximately 64°F) is reached. Master two-position outside air duct thermostat T-3 reverses action of T-2 when outside air temperature rises to 80°F.

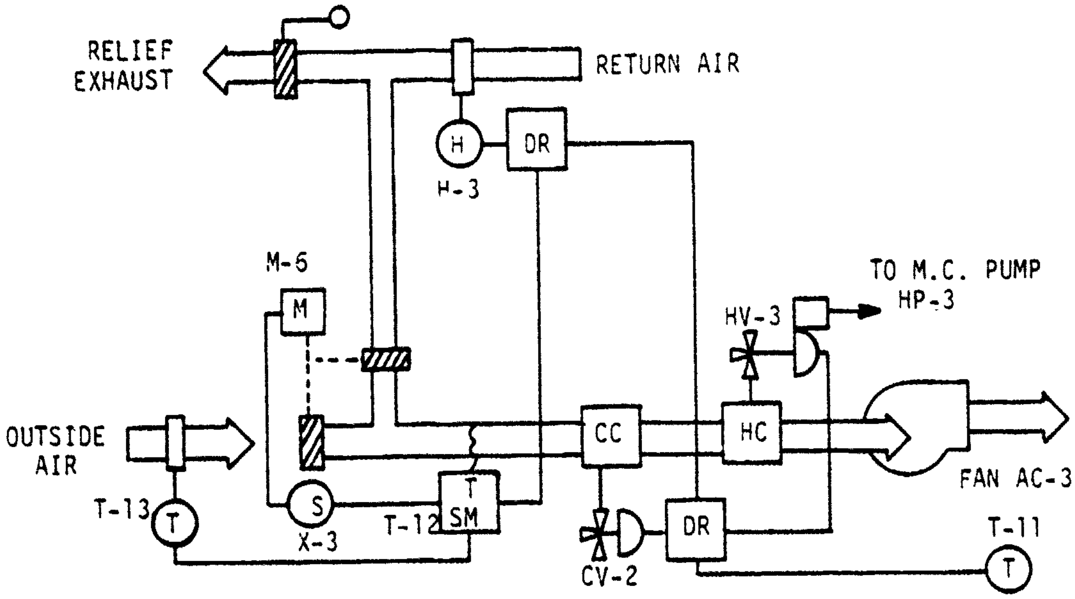
(B) Zone heating thermostat T-1 gradually opens heating coil valve HV-1 as room temperature falls below set point and shall operate cooling coil valve through relay to maintain spaces at 80°F. Auxiliary switches stop coil circulating pumps when valve reaches the position of no heat required.

(C) Modulating duct humidistat H-1 over-rides temperature controller T-2 to close outside air damper first and then opens cooling coil valve CV-1 as return air relative humidity rises above 50 percent. Humidistats shall be adjustable to maintain space at a minimum of 35 percent relative humidity.

(D) Relief exhaust damper maintains a positive pressure of 0.1 inch in the system.

(E) Manual switch X-1 positions dampers as required by T-2 when set at "normal"--when set on "emergency", bypasses temperature controller T-2 and opens outside air damper to minimum position.

Figure 4. Control Schematic AC-1



AIR CONDITIONING UNIT AC-3 CONTROL
McClellan AFB, CA.
Radar Approach Control Facility

Control System for Air conditioning Unit AC-3:

(A) Mixed air temperature is controlled by modulating duct thermostat T-12 which, at winter design temperature, operates damper motor M-6, for minimum outside air and maximum return air. As outside air temperature rises, T-12 gradually opens the outside air damper and closes the return air damper until the outside air damper is wide open when the set point (approximately 64°F) is reached. Master two-position outside air duct thermostat T-3 reverses action of T-12 when outside air temperature rises to 80°F.

(B) Zone heating thermostat T-11 gradually opens heating coil valve HV-3 as room temperature falls below set point and shall operate cooling coil valve through relay to maintain spaces at 80°F. Auxiliary switches stop coil circulating pumps when valve reaches the position of no heat required.

(C) Modulating duct humidistat H-1 over-rides temperature controller T-12 to close outside air damper first and then opens cooling coil valve CV-2 as return air relative humidity rises above 50 percent. Humidistats shall be adjustable to maintain space at a minimum of 35 percent relative humidity.

(D) Relief exhaust damper maintains a positive pressure of 0.1 inch in the system.

(E) Manual switch X-3 positions dampers as required by T-12 when set at "normal"--when set on "emergency", bypasses temperature controller T-12 and opens outside air damper to minimum position.

Figure 5. Control Schematic AC-3

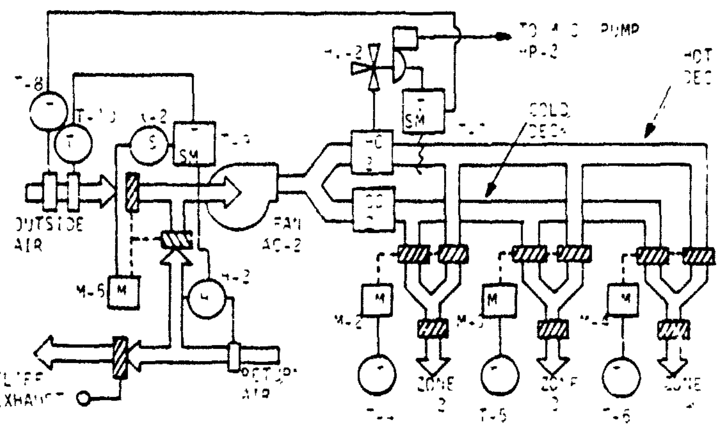
(temperature of air passing through the heating coil) at the set point by operating the heating coil control valve. An outside air duct master modulating thermostat lowers the set point of the submaster modulating duct thermostat as the outside air temperature rises.

Room (zone) temperature is maintained at the set point by modulating zone thermostats which operate zone-mixing damper motors. These dampers combine heated and cooled air in the proper proportions to maintain the required room temperature. Return air humidity is regulated with the outside-air intake damper, which is controlled by the modulating duct humidistat.

A switch mounted on the heating coil water valve stops the air handler hot water circulating pump when the valve reaches the closed position (no heat input required). Water flow rate through the cooling coil is uncontrolled since the zone mixing dampers control the air rates across the cooling coil. A schematic describing the operation of AC-2 is provided in Figure 6.

Air handling unit AC-4 is also a multi-zone unit. This air handler provides conditioned air to six zones in the building. The unit's controls are similar to the controls used in AC-2 except for the addition of a load analyzer which reduces overall energy consumption. A submaster modulating duct thermostat maintains the hot deck temperature just high enough to satisfy the coldest zone heating requirement determined by the load analyzer. A dual-input controller is used to maintain the cold deck temperature just low enough to satisfy the hottest zone cooling requirement determined by the load analyzer. Hot deck and cold deck temperatures are controlled by the heating coil control valve and cooling coil control valve positions. A switch mounted on the heating coil valve stops the air handler hot water circulating pump when the valve reaches the closed position.

Room (zone) temperature is maintained at the set point by modulating zone thermostats which operate zone mixing damper motors. These dampers combine heated and cooled air in the proper portions to maintain the required room temperature. Return air humidity is regulated with the outside air intake damper controlled by the modulating duct



AIR CONDITIONING UNIT AC-2 CONTROL
McClellan AFB, Ca.
Radar Approach Control Facility

Control System for Air Conditioning Unit AC-2:

(A) Submaster modulating duct thermostat T-7 maintains hot deck temperature at set point by operating heating coil control valve HV-2. Outside air duct master modulating thermostat T-8 lowers the set point of T-7 as outside air temperature rises. Auxiliary switch on valve HV-2 stops hot water coil circulating pump when valve reaches the position of no heat required.

(B) The cooling coil is not controlled.

(C) Mixed air temperature is controlled by submaster modulating duct thermostat T-9, which, at winter design outside temperature, operates damper motor M-5 for minimum outside air and maximum return air. As outside air temperature rises, T-9 gradually opens the outside air damper and closes the return air damper until the outside air damper is wide open when the set point (approximately 64°F) is reached. Master two-position outside air duct thermostat T-10 reverses action of T-9 when outside air temperature rises to 80°F.

(D) Room temperature is maintained at set point by modulating room thermostats T-4, T-5, and T-6, which operate zone mixing damper motors M-2, M-3, and M-4.

(E) Modulating duct humidistat H-2 over-rides temperature controller T-9 to close outside damper as return air relative humidity rises above 50 percent. Humidistat shall be adjustable to maintain space at a minimum of 35 percent relative humidity.

(F) Relief exhaust damper maintains a positive pressure of 0.1 inch in the system.

(G) Manual switch X-2 at "normal" positions dampers as required by T-9, on "emergency" bypasses temperature controller T-9, and opens outside air damper to minimum position.

Figure 5. Control Schematic AC-2

humidistat. A schematic describing the operation of AC-4 is provided in Figure 7.

c. Boilers

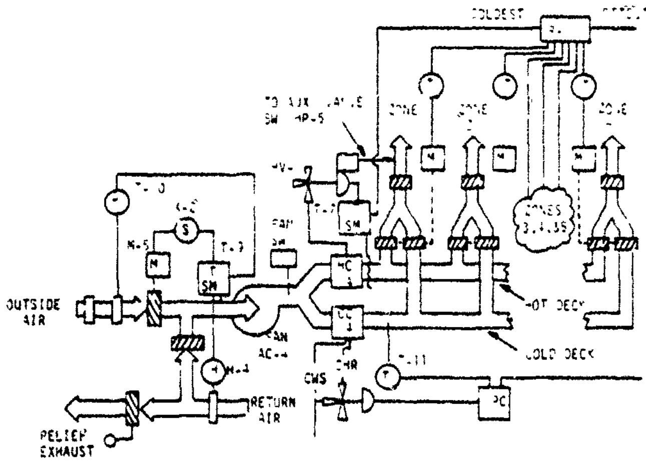
The two natural gas fueled boilers HB-1 and HB-2 are operated by temperature controllers located in the hot water outlet line. When the outlet water temperature drops below the set point (190-200^{O}F) the temperature controller opens the main gas valve and allows fuel to be admitted to the main burners of HB-1 or HB-2. Although piping from each boiler is connected in series, normal practice is to operate only one boiler at a time. Each boiler is equipped with the normal flame safeguard, pressure relief, and low water safety systems.

d. Water Chillers

The two equipment room installed chillers WC-1 and WC-2 (25 ton units) are started or shut down in sequence by a master chilled water controller. The controller is set to maintain a 58^{O} chilled water return temperature. An adjustable time delay relay prevents more than one chiller unit from starting at the same time. The order in which the units operate is selected by a manual sequence transfer switch. A return-water flow switch prevents the chiller compressors from operating when none of the chilled water circulating pumps are running. Interlocks also prevent each compressor from operating.

Temperature controllers shut off the cooling tower fans when the condenser water temperature drops below 75^{O}F. Low temperature controllers are also used to stop the chiller units when the chiller water discharge temperature decreases to 42^{O}F. Other temperature controllers placed in the chilled water discharge lines operate compressor unloaders to maintain a 48^{O}F output water temperature.

The third chiller WC-3 (23-ton unit) is started by the master chilled water controller when the two 25-ton units cannot maintain the 58^{O}F return water temperature. A sequential control system opens two motorized block valves (one in the chilled water supply line and the other in the chilled water return line), starts chilled water pump CP-3, and activates the chiller control circuit.



AIR CONDITIONING UNIT AC-4 CONTROL
McClellan AFB, Ca.
Radar Approach Control Facility

Control System for Air Conditioning Unit AC-4:

(A) Submaster modulating duct thermostat T-7 maintains hot deck temperature just high enough to satisfy coldest zone as determined by load analyzer R-1. Auxiliary switch on valve HV-2 stops hot water coil circulating pump when valve reaches the position of no heat required.

(B) The cooling coil is controlled by dual input controller to maintain cold deck temperature (T-11) just low enough to satisfy hottest zone as determined by load analyzer R-1.

(C) Mixed air temperature is controlled by submaster modulating duct thermostat T-9, which, at winter design outside temperature, operates damper motor M-5 for minimum outside air and maximum return air. As outside air temperature rises, T-9 gradually opens the outside air damper and closes the return air damper until the outside air damper is wide open when the set point (approximately 64°F) is reached. Master two-position outside air duct thermostat T-10 reverses action of T-9 when outside air temperature rises to 80°F.

(D) Room temperature is maintained at set point by modulating room thermostats which operate zone mixing damper motors in AC-4.

(E) Modulating duct humidistat H-4 over-rides temperature controller T-9 to close outside damper as return air relative humidity rises above 50 percent. Humidistat shall be adjustable to maintain space at a minimum of 35 percent relative humidity.

(F) Relief exhaust damper maintains a positive pressure of 0.1 inch in the system.

(G) Manual switch X-2 at "normal" positions dampers as required by T-9,--on "emergency" bypasses temperature controller T-9, and opens outside air damper to minimum position.

Figure 7. Control Schematic AC-4

7. DOMESTIC HOT WATER SYSTEM

Domestic hot water is produced in a 4.5 kW (30gph) electric hot water heater. The heater circuit is equipped with a 1/12 hp, 3 gpm hot water circulation pump to maintain hot water at user locations.

8. MODIFICATION PROJECT SMA 62-9

The building HVAC system is scheduled to be modified prior to the start of the Fuel Cell Operational Feasibility field test phase by project SMA 62-9. This project will remove water chillers WC-1 and WC-2 and replace them with a single reciprocating-type chiller. The two cooling towers CT-1 and CT-2 will be replaced with two new cooling towers. Heating boiler HB-1 will be removed and the shed-mounted unit HB-2 will be installed in the equipment room. Reference 2 contains details of the modification project. These changes should not affect the proposal fuel cell installation concepts or the suitability of the proposed site for fuel cell testing.

SECTION III

FUEL CELL DESCRIPTION

The fuel cells which will be used in the Gas Utility 40-kW Fuel Cell Operational Feasibility Program are designed and manufactured by the Power Systems Division of the United Technologies Corporation (UTC). These are phosphoric acid type fuel cells and are designed to produce electricity and heat by an electrochemical reaction using natural gas and air.

A detailed description of the 40-kW fuel cell is contained in the "On-site 40-Kilowatt Fuel Cell Power Plant Model Specification" FCS-1460 Prepared for: U.S. Department of Energy and the Gas Research Institute by the United Technologies Power Systems Division South Windsor, Conn. (Reference 3).

A simplified description is presented in this section to provide the reader with a basic understanding of fuel cell principles and to elaborate on the operating characteristics which must be understood before the various site installation alternatives can be evaluated.

1. PLANT DESCRIPTION

The 40-kW UTC fuel cell power plant is pre-packaged in a 62" wide x 78" high x 108" long enclosure which is designed for outdoor installation. The enclosure weighs approximately 7000 pounds and is equipped with lifting lugs to facilitate transportation. The enclosure contains all components necessary for fuel processing, power generation, and heat recovery.

Major components of the power plant (as defined by UTC) are listed below:

a) Fuel processor (including preprocessor)
b) Power section
c) Thermal management subsystem (including heat recovery)
d) Power conditioner

Simplified block diagrams of the system are shown in Figures 8 and 9; component locations within the package are shown in Figure 10; and Figure 11 shows overall dimensions of the unit. A detailed power plant schematic is shown in Figure 12.

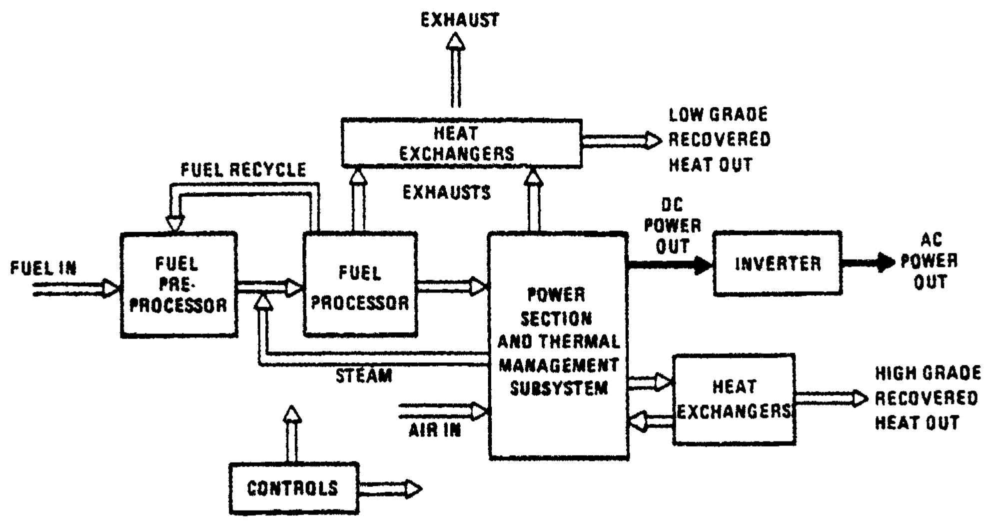


Figure 8. Simplified Block Diagram of 40-kW Fuel Cell
(From Reference 3)

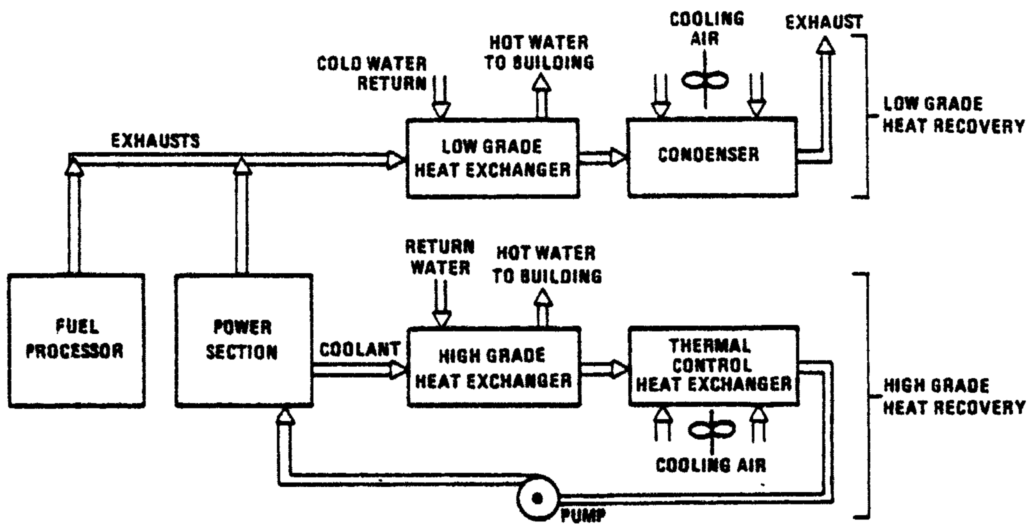


Figure 9. Heat Recovery System Diagram
(From Reference 3)

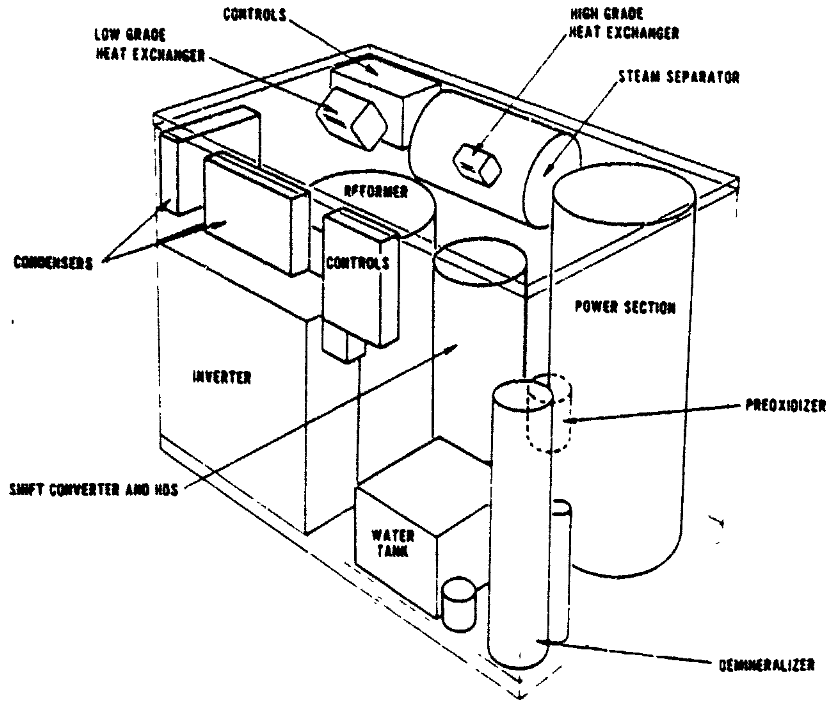


Figure 10. Major Component Locations
(From Reference 3)

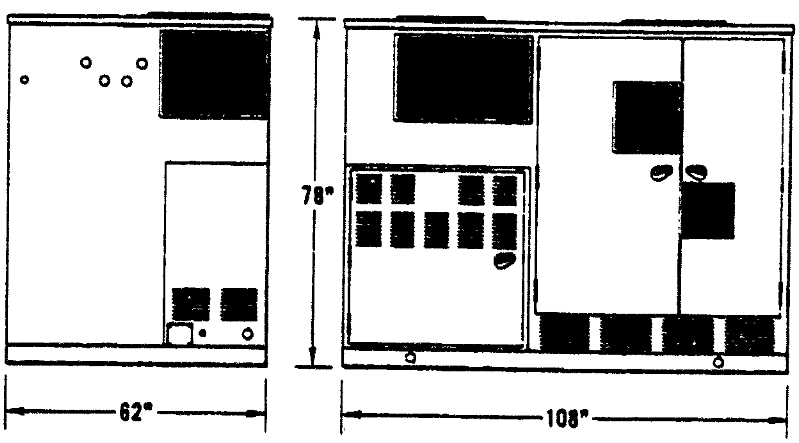


Figure 11. Power Plant Dimensions
(From Reference 3)

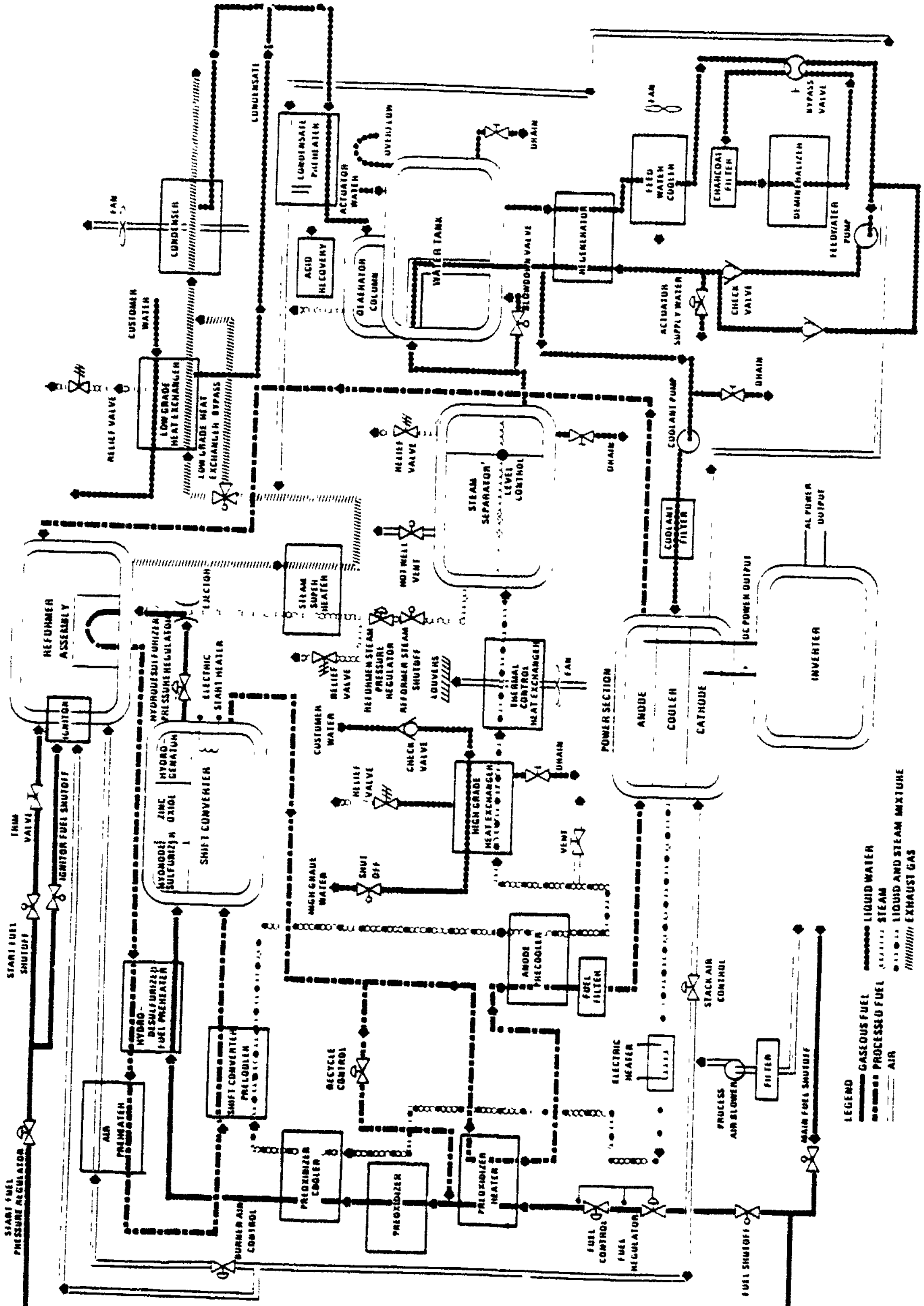


Figure 12. Power Plant Schematic (From Reference 3)

The UTC fuel cell is designed for high fuel conversion efficiencies. At output electrical power levels above 50% of rated capacity, approximately 40% of the BTU content of the fuel is converted into electrical energy and 40% is released in the form of recoverable by-product heat. At lower electrical power levels, the amount of energy released as recoverable by-product heat is reduced until no recoverable heat is available at electrical power output levels below 20% of the rated capacity of the machine.

Installation of the fuel cell package in a user facility is relatively simple since connections for fuel, electrical power, water, drains, and exhausts are minimized. Details of these interface connections are fully described in Reference 3.

2. PROCESS DESCRIPTION

Natural gas or peak shaved gas is fed to the preoxidizer and hydrodesulfurizer sections of the unit (see Figure 12) where free oxygen and sulfur compounds are removed from the fuel. The fuel is then mixed with steam and catalytically converted to a hydrogen rich gas in the reformer and shift converter. The hydrogen rich gas is then electrochemically combined with oxygen from an external air stream in the power section to produce a direct electrical current and water. The unreacted hydrogen from the power section is reacted with air in the reformer burner to produce the thermal energy required to generate steam used in the reformer. The direct electric current produced in the power section is converted to a three-phase alternating current in the invertor section.

Hot exhaust gases from the reformer burner and power section are routed to a formed plate heat exchanger (low-grade heat exchanger). The low-grade heat exchanger transfers heat from the exhaust gases to an external water loop if by-product heat is to be utilized in the using facility. If by-product heat is not required or insufficient heat is removed by the external water loop, an air cooled heat exchanger (condenser) is used to drop the exhaust temperature to approximately $120^{O}F$ before the exhaust is discharged to the atmosphere. Steam in the exhaust gas is condensed in either the low-grade heat exchanger and/or condenser and piped to the power section coolant loop.

A second source of by-product heat is obtained from water used to control the power section temperature. The heat generated in the electrochemical reaction process is removed by circulating water through the power section. This water (part of which is vaporized in the power section) is routed through two heat exchangers. The first, a formed-plate heat exchanger (high-grade heat exchanger), provides the means to transfer heat to a user-supplied external water loop. The second, an air-cooled heat exchanger (thermal control heat exchanger), removes excess heat from the water/steam mixture if sufficient heat is not removed in the user external water loop. The water/steam mixture is then piped to a steam separator where the steam is removed and routed to the reformer. The remaining water is combined with condensate from the exhaust gas which was routed through the low-grade heat exchanger/air-cooled condenser and pumped back into the power section.

Since quality (% steam vs. % water) of the steam mixture feed to the steam separator is critical, the thermal management control system will shut off user external water flow to the high-grade heat exchanger if too much heat is removed in the high-grade heat exchanger.

3. BY-PRODUCT HEAT RECOVERY

As previously discussed, the low-grade heat exchanger provides a means to transfer heat from the hot gases generated within the fuel cell during the fuel reforming and electrochemical energy conversion processes to a user utility system. This heat transfer is usually accomplished through an external water loop in which water from the user facility is pumped through the low-grade heat exchanger and returned to the facility at a higher temperature.

The high-grade heat exchanger provides a means to transfer heat from the power section cooling loop to a user utility system. Heat transfer is accomplished as described above through an external water loop in which water from the user facility is pumped through the high-grade heat exchanger and returned to the facility at a higher temperature.

Performance parameters for the low-grade heat exchanger are shown in Figure 13. This figure can be used to predict the amount of heat transfer or temperature rise of the external supply water when various

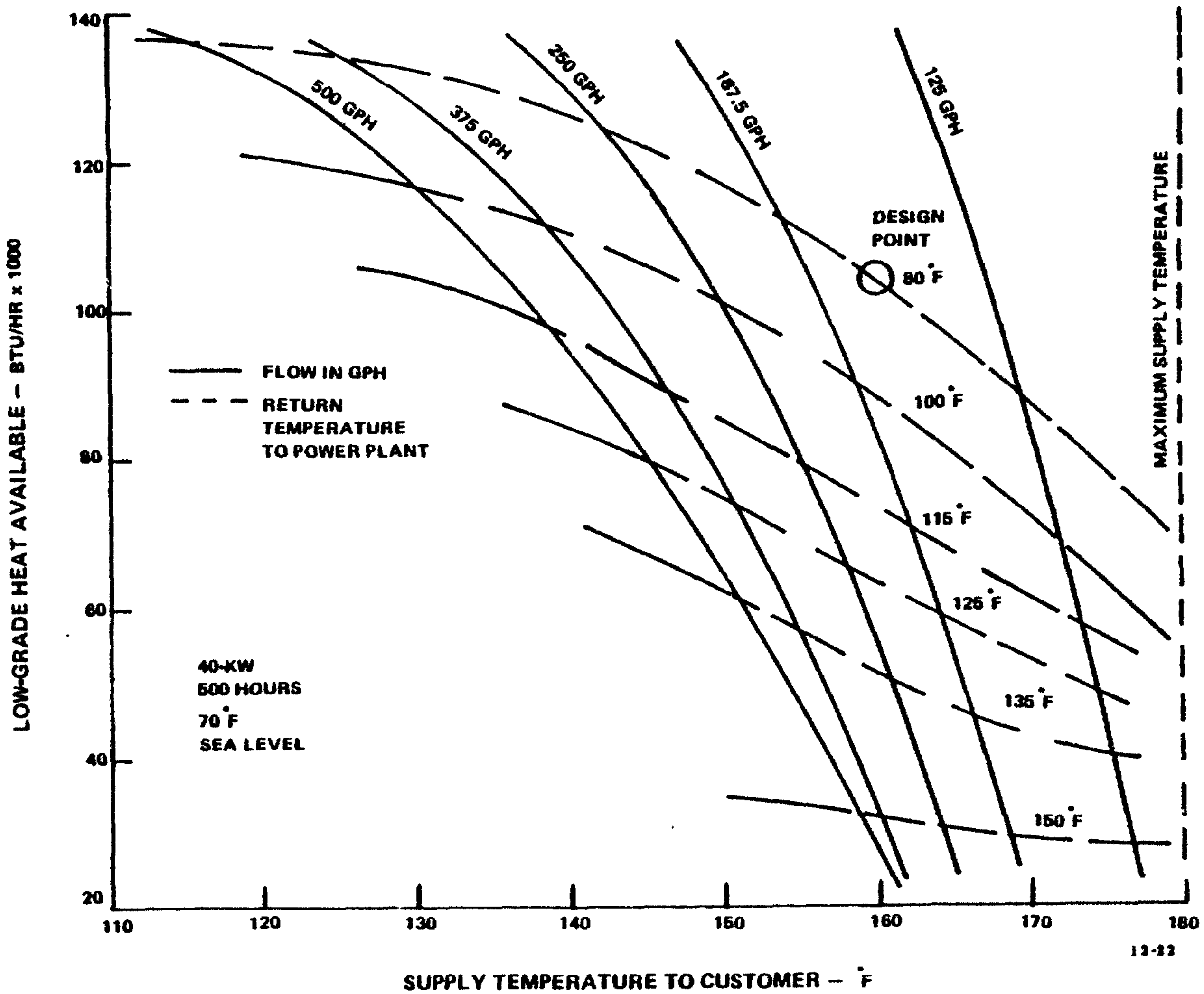


Figure 13. Low-Grade Heat Exchanger Performance (From Reference 3)

inlet water temperatures and flow rates are known. The design point (point used to calculate overall fuel cell thermal efficiency) is based on heating 2.5 gpm of 80°F water to 160°F. Maximum outlet water temperature is limited to 180°F.

Actual performance data for the high grade heat exchanger are not presently available from UTC. However, the shape of the performance curves should be similar for both the low-grade and high-grade heat exchangers. The design point for the high-grade heat exchanger is based on heating 2.0 gpm of 80°F water to 160°F. At reduced water flow rates discharge temperatures up to 275°F are possible. In lieu of detailed performance curves for the high-grade heat exchanger, data shown in Figure 14 will be used in this report to estimate the available heat from the power section cooling loop.

As seen from Figure 13, the amount of heat which can be transferred to an external water circuit decreases as the inlet water temperature increases or as outlet water temperatures are increased. Consequently, fuel cell thermal efficiency decreases under these conditions.

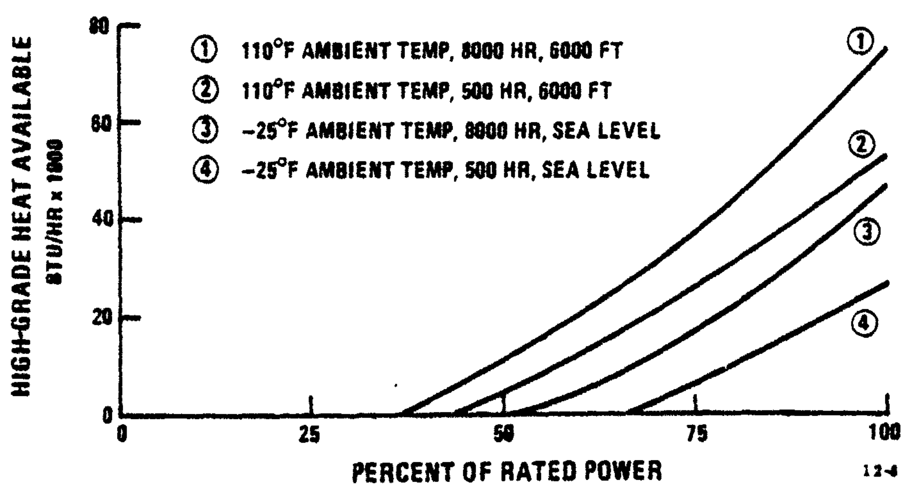


Figure 14. High-Grade Heat Availability
(From Reference 3)

SECTION IV

FUEL CELL INTEGRATION CONCEPTS

Based on the preceding descriptions of the fuel cell and Building 1099 utility systems, several methods of utilizing the electrical and thermal output of two 40-kW fuel cell power plants are possible. The electrical output can supply part of the building's electrical needs and by-product heat can augment the heating system or power a thermally driven cooling system. These installation concepts are described below.

1. ELECTRICAL

The fuel cells can be tied into the building electrical system in either of two ways. The cells can be operated in parallel with commercial power or tied directly to individual loads. Either method is compatible with building voltage-phase relationships since cell output connections match the three-phase, four-conductor system used throughout the main switchboard and facility.

a. Parallel Connection

In the first approach, the two cells are tied to the facility's main switchboard through a grid connect system which is currently under development by UTC (see Figure 15). This system will have the capability to control up to six fuel cells in parallel operation. The UTC grid system must, however, be modified by the addition of several specialized electrical components.

Current sensors coupled with fast-acting automatic disconnect switches will be required to disconnect the cells from the switchboard during commercial power outages. If the cells are not disconnected during these outages, the cells could essentially see an infinite load on the commercial side of the bus. In addition, the normal building load exceeds the combined output of the two fuel cells.

Impedance matching devices would also be required in the connecting circuit. These devices will allow the output of the cells to be delivered to the switchboard without being overridden by the much larger capacity of the commercial power supply.

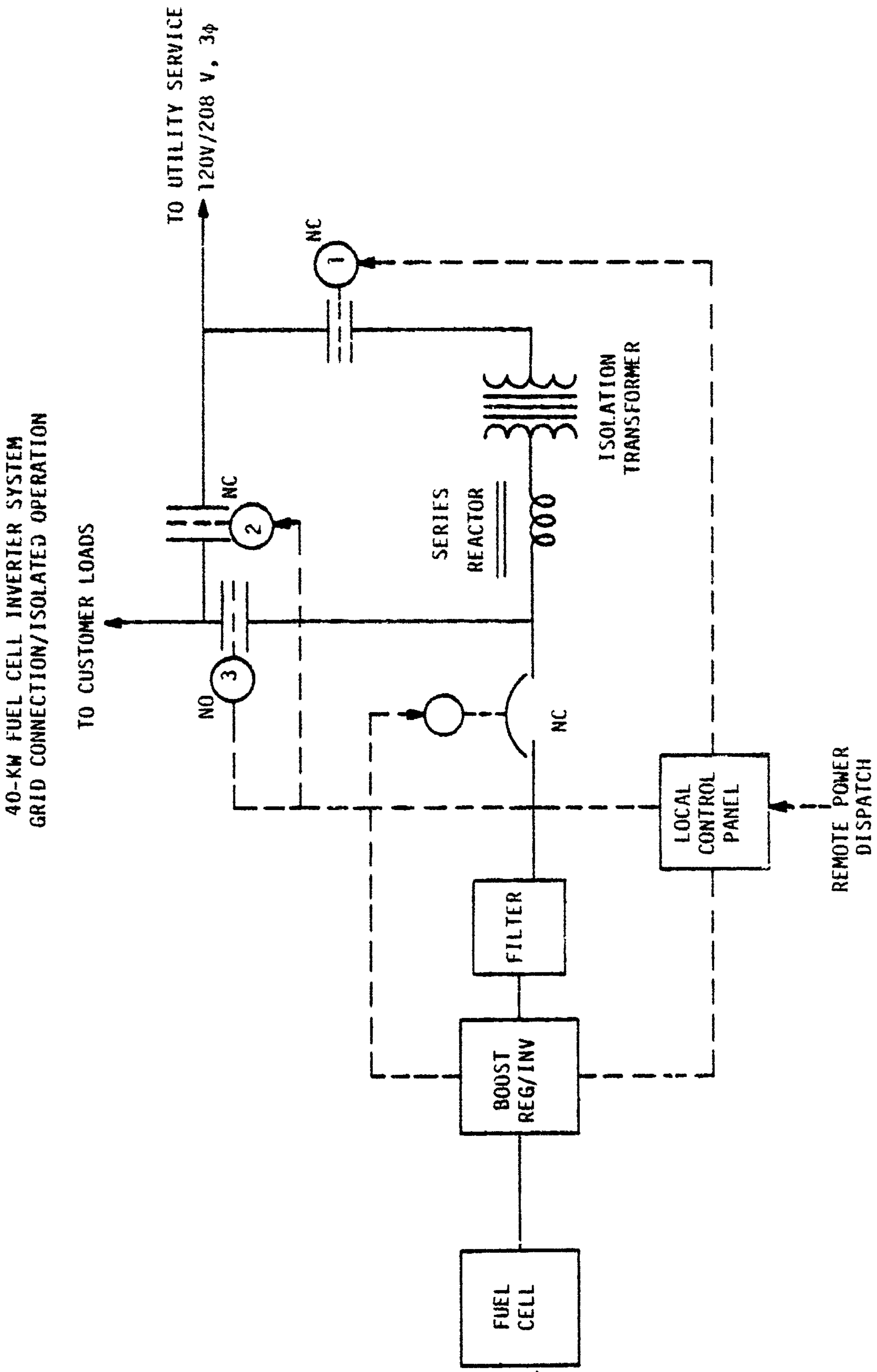


Figure 15. Modified Grid-Connect Single-Line Diagram

b. Individual Bus Connection

The second method of connecting fuel cell electrical power to the facility distribution system does not require the use of specialized electrical components. The output from the two fuel cells would be tied directly to specific circuits through automatic transfer switches. The fuel cell output would be tied to one side of the automatic transfer switch(s) and the other side would be supplied by commercial power. In the event of a fuel cell power failure the switch(s) would automatically reposition and the load would be carried by commercial power. The fuel cells would continue to carry the circuit when commercial power is lost.

The fuel cells could be operated in parallel with each other by using the UTC grid system described in Figure 15 to supply 80 kW through one transfer switch or the cells could be set up independently using two transfer switches with up to 40 kW supplied to each switch. The circuits to be powered by the fuel cells (operating separately or in parallel) would be selected to match the output power capability of the cells and be compatible with the output voltage waveforms of the cells. The latter constraint is mentioned since total harmonic distortion of the fuel cell waveforms is in the 5-10% range while generator power and commercial power waveforms usually contain less than 2% total harmonic distortion.

By segregating some of the loads on the emergency power and commercial power buses with the addition of several automatic transfer switches, the fuel cells and emergency power generator could be used to supply the entire building load during commercial power outages. The segregation would also eliminate the need to operate the fuel cells in parallel with the generator.

2. HEATING

a. Return Water

Several methods of utilizing the fuel cell thermal output in Building 1079 are available. The simplest of these methods is to route part of the HVAC system return hot water through the fuel cell heat exchangers. All piping connections would be made upstream of the existing gas fired boilers (See Figure 16). This concept would use the fuel cells to increase the return water temperature up to the limits of the cells and the boilers would provide any additional heat required in the facility. A major advantage of this concept is that no changes will be required in the existing boiler control system.

Since the fuel cell formed-plate heat exchangers are designed for small water flow rates (See Figure 13) and the HVAC hot water system return water flow rate will approach 33 gpm, only a portion of the return water can be passed through the fuel cell heat exchangers. Figure 16a illustrates a piping arrangement in which HVAC heating coil return water is routed first through the low-grade heat exchangers and then through the high-grade heat exchangers.

A variation in this scheme, shown in Figure 16b, will increase the amount of heat transferred in the high-grade heat exchanger. In this arrangement, a portion of the return water is routed directly to the high-grade exchanger without passing through the low-grade heat exchanger. This approach provides lower temperature inlet water to the high-grade heat exchanger. As a result, the temperature difference across the heat exchanger is increased and more heat can be transferred with the same water flow rate.

The thermal efficiencies of these two installation concepts are low. Since HVAC return water temperatures range between 150^{O}F and 170^{O}F, very little heat can be transferred to the return water by the fuel cells.

From Figure 13 only 30,000 Btu/hr per cell can be transferred to the return water by the low-grade heat exchanger if a facility return water temperature of 150^{O}F is assumed. At the upper range of return water temperature almost no heat can be transferred by the low-grade heat exchangers. However, some increase in heat transfer could be obtained by increasing the return water flow rates through the low-grade heat exchanger. If a water flow rate of 2.5 gpm is assumed, 30,000 Btu/hr is added to the return water while an 8.0 gpm flow rate adds 43,000 Btu/hr to the return water. Final discharge temperature of the return water would range between 158^{O}F and 180^{O}F with the highest temperature produced at the lower flow rate. These heat rates are based

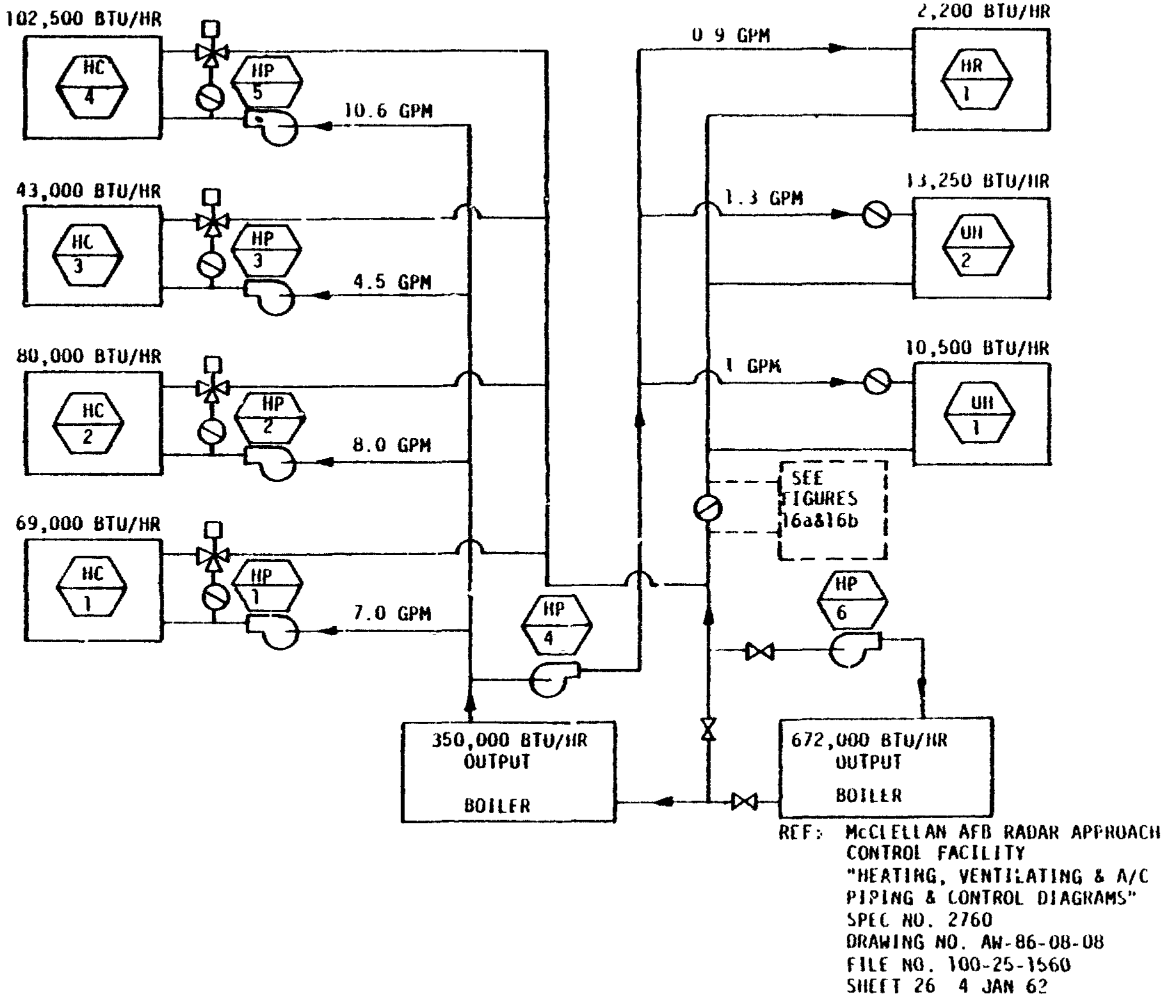


Figure 16. Test Site Hot Water System Block Diagram Modified to Reflect Fuel Cell Heat Recovery

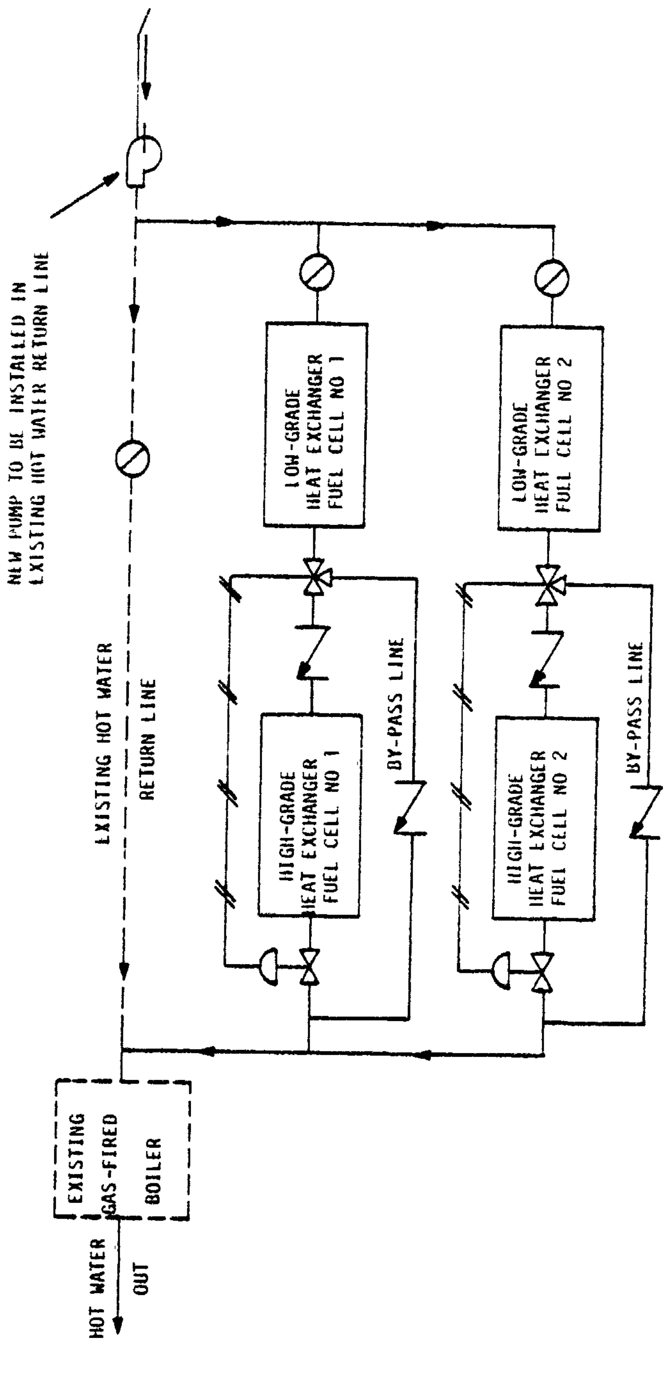


Figure 16a. Return Water Heating (Option 1)

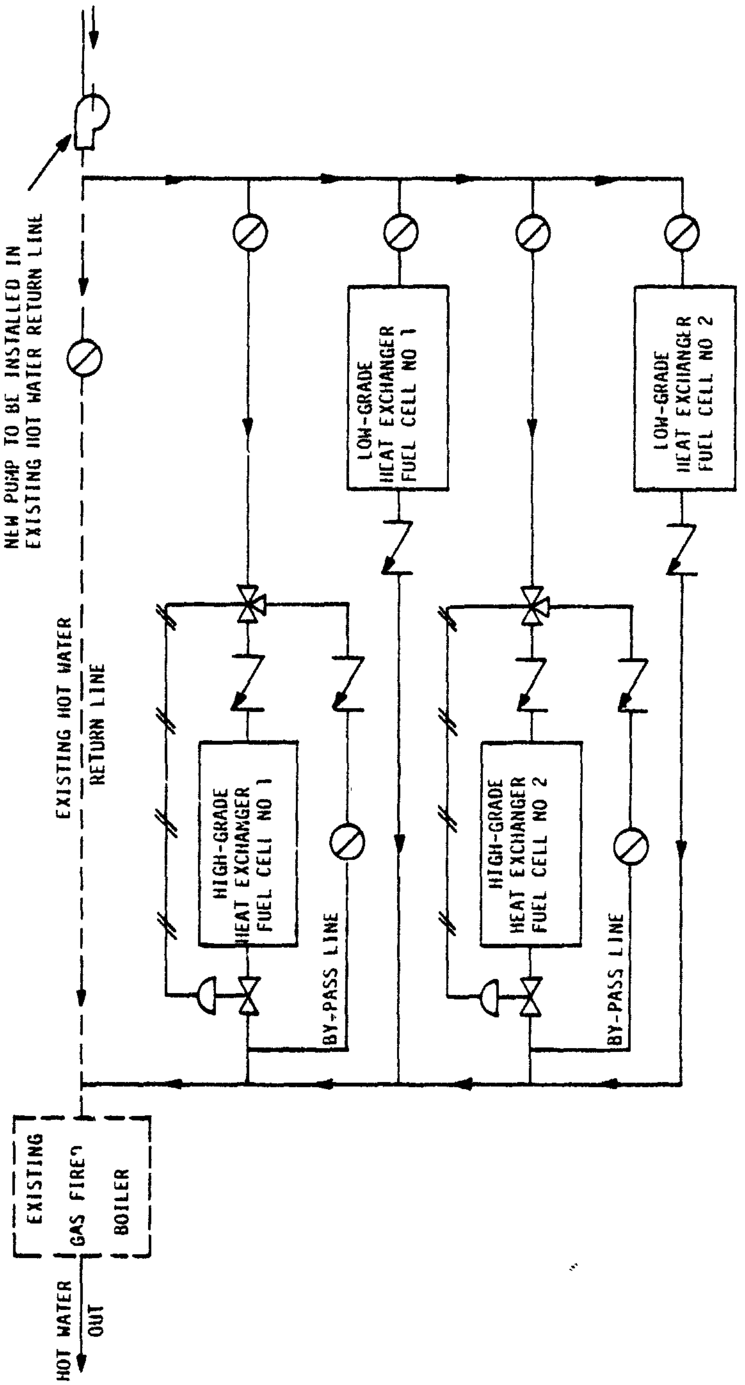


Figure 16b. Return Water Heating (Option 2)

on 150^{O}F return water temperature to the inlet side of the low-grade heat exchanger.

A similar evaluation of the high-grade heat exchanger cannot be performed since the high-grade heat exchanger performance curve is not presently available from UTC. For the purposes of this study the high-grade heat exchanger will be assumed to add 50,000 Btu/hr to the return water regardless of flow rate and return water temperature.

b. Return Air Direct Heating

Higher fuel cell thermal efficiencies can be realized if the temperature of the facility water supplied to the fuel cell is lowered. One method of producing this lower temperature water is to install highly efficient air-to-water multi-pass heat exchangers in the facility return airducts. A separate water system (not tied to the existing building hot water system) would be used to supply fuel cell heated hot water to the duct-mounted heaters. The cold building return air would then be heated in these duct-mounted heat exchangers. The resulting heat exchange would produce a lower outlet water temperature than the currently used air-to-water heat exchangers.

Currently HVAC return air temperatures (See Table 2) range from 53^{O}F to 64^{O}F and the air handler discharge air temperatures range from 57^{O}F to 81^{O}F. These air temperatures will produce low temperature water to the fuel cells provided the heat exchanger surface area is sufficiently large. Using a 10^{O}F differential approach temperature, the highest return water temperature would be 91^{O}F.

From the low-grade heat exchanger performance curve (Figure 13), assuming 91^{O}F return water at an 8.0 gpm rate, approximately 125,000 Btu/hr could be transferred to the return water. With these heat rates it can be seen (from Figure 2) that additional heat would be required from the existing boiler system. Figure 17 describes a concept in which the new fuel cell heat exchangers could supply hot water to new duct-mounted heat exchangers.

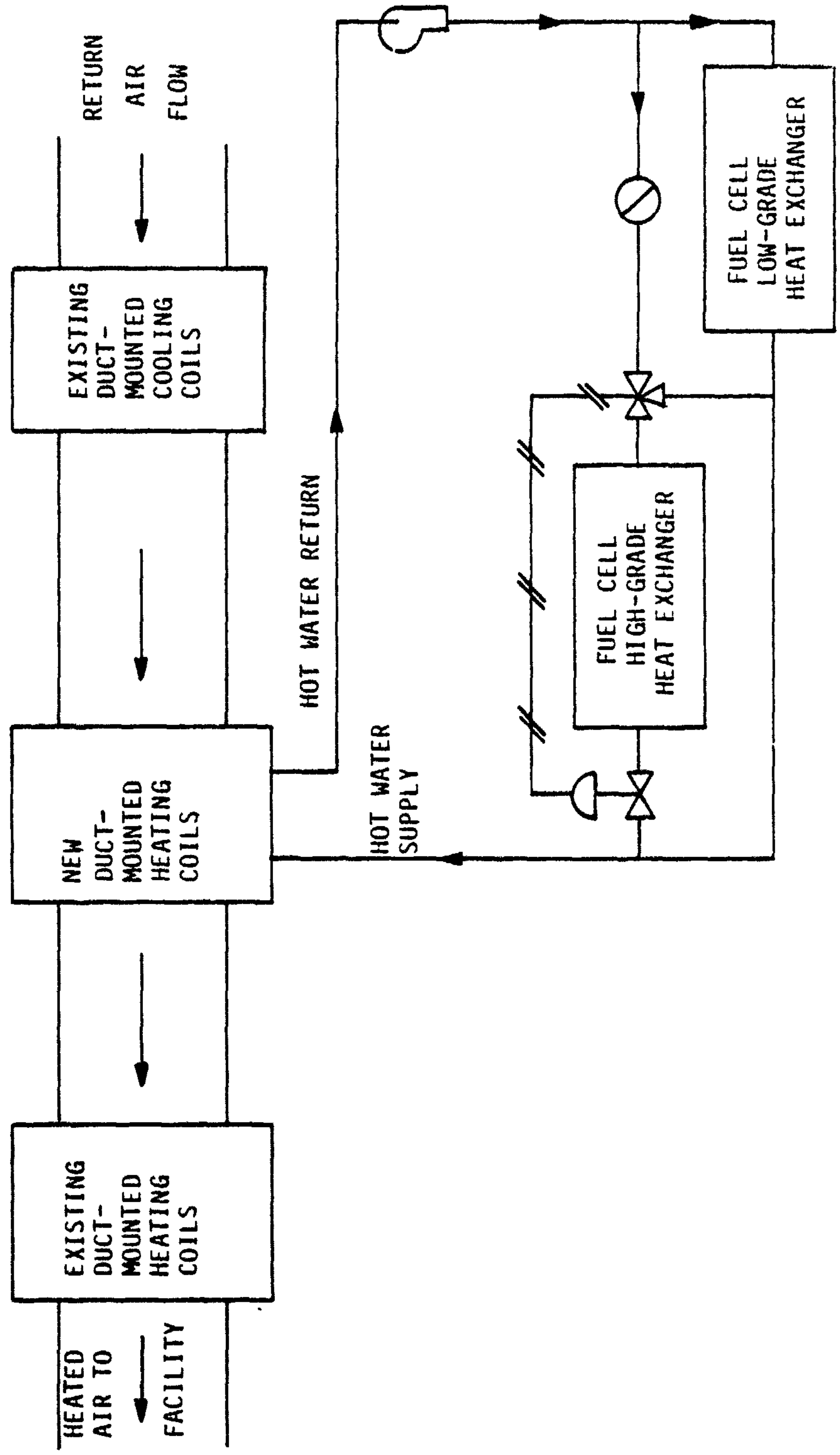


Figure 17. New Duct-Mounted Heat Exchanger-Hot Water Supplied from Fuel Cell

3. COOLING

a. Absorption Chiller

Fuel cell by-product heat can be used to supplement the building cooling requirements when used in conjunction with an absorption chiller. In this arrangement, fuel-cell-produced hot water would evaporate the refrigerant from an absorbent fluid and the resulting refrigeration effect could be used to remove heat from the facility chilled water system.

The operating principle of an absorption chiller is relatively simple. A working fluid (ex. lithium bromide/water solution) is first pumped through a heat exchanger where the fluid is preheated by the hot absorbent (lithium bromide) returning from the generator section of the unit. Additional heat is added to the working fluid in the generator section by hot water supplied from an external source (in this case, fuel cells). This additional heat drives the refrigerant (water) from the absorbent (lithium bromide solution). The hot lithium bromide then flows to the absorber through a liquid/liquid heat exchanger and the vaporized refrigerant flows to the condenser. The latent heat of vaporization is removed from the refrigerant by condenser water flowing through the condenser tubes. The condensed refrigerant then passes through a metering device into the evaporator section where heat from an external chilled water circuit (building chilled water system) is absorbed by the refrigerant. This heat vaporizes the refrigerant. The refrigerant vapor and absorbent are then re-combined fluid (lithium bromide/water solution) flows back to the circulation pump to re-initiate the cycle.

A number of companies are not involved in the manufacture of small absorption chillers which could be operated with fuel-cell-heated water. One of these units, which is manufactured for operation with solar-heated water, has heat input requirements which match the 40-kW fuel cell thermal output. The unit is prepackaged in a 29" x 30" x 68" cabinet with connections for hot water, chilled water, condenser cooling water, and electrical input. This unit can easily be integrated into the RAPCON chilled water system.

By routing approximately 7.0 gpm of facility HVAC chilled water through the absorption chiller cooling coils, three tons (per 40-kW fuel cell) of refrigeration effect can be achieved. The chilled water would be obtained from the existing chilled water return line just upstream of the existing chillers. The water after passing through the absorption chiller would be reinjected into the system upstream to the existing water chillers and downstream of the "take out" connection. The hot water needed to drive the absorption chiller would be supplied by the fuel cells in a manner similar to that described in subsection 2 of Section IV where the fuel cell was used to supplement the facility hot water system. Condenser water for the absorption chiller condenser coils can be supplied by the existing facility cooling towers with only minor modifications to the cooling tower piping system.

Performance curves for a typical absorption chiller in this size range indicate that as the temperature of the water supplied to the generator coils increases the refrigeration capacity increases. For a three-ton refrigeration effect, 11 gpm of 195^{O}F fuel-cell-heated water will be required. Since the return water temperature from the generator to the fuel cell is relatively high (185^{O}F), only heat from the high-grade heat exchanger can be utilized (Thermal stresses limit the low-grade heat exchanger to a maximum 180^{O}F delivered water temperature).

With two fuel cells, six tons of refrigeration can be delivered to the building. This capacity is based on the 50,000 Btu/hr assumed heat rate for the high-grade heat exchanger since the actual heat exchanger performance curves are not available at this time.

Figure 18 illustrates a method for using two such absorption chillers and two 40-kW fuel cells to supplement the building cooling load.

b. Jet Refrigeration

An alternative method of using fuel cell by-product heat to supplement the facility cooling load would be to drive a vapor jet refrigeration cycle. This cycle is similar to the standard single fluid, compressor-driven, refrigeration cycle except the compressor is replaced by a vapor-jet pump. The vapor-jet pump refrigeration cycle employs a

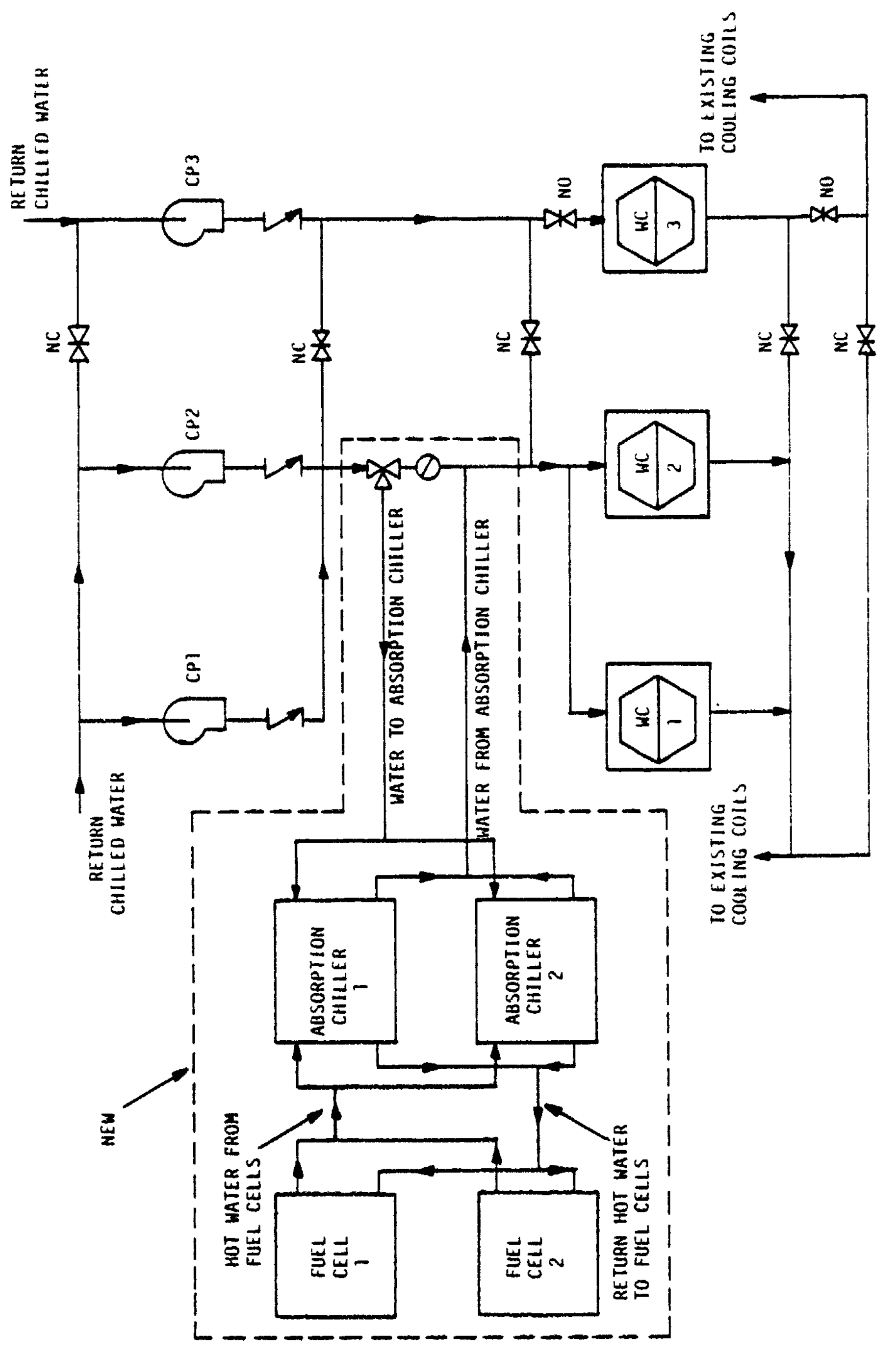


Figure 18. Block Diagram Illustrating Fuel-Cell Heat and Absorption Chillers to Augment Existing Cooling System

pump to pressurize the working fluid and heat from an external source (in this case, fuel cell heat) to vaporize the fluid. The high pressure saturated vapor is expanded through a convergent/divergent nozzle into a mixing chamber then exhausted through the diffuser section to a condenser. Part of the condensed fluid is recycled to the pressurizing pump and the remaining fluid is admitted into an evaporator through an expansion valve. Heat is the absorbed from the facility HVAC chilled water system in the evaporator which in turn vaporizes the working fluid. The vaporized fluid is drawn into a mixing chamber and re-combined with the fluid vapor passing through the convergent/divergent nozzle.

Coefficients of performance for this system are similar to absorption chiller coefficients of performance. Operating temperatures of the external heat source are also similar. As a result, only the fuel cell high-grade heat exchangers can be used to supply hot water to the vapor-jet pump heating loop. Approximately six tons (combined output from two fuel cells) of refrigeration can be produced with the jet pump refrigeration system.

A detailed description of the vapor-jet pump cycle is contained in a NASA Technical Support Package on "Solar Powered Jet Refrigerator" (see Reference 4).

Integration of the vapor-jet pump refrigeration system into the HVAC system would be accomplished in a manner similar to the method described in paragraph 3 for the absorption chiller units.

SECTION V

INSTRUMENTATION

Data acquisition requirements for the 40-kW Fuel Cell Operational Feasibility Program have been specified by the DOE/Gas Research Institute Fuel Cell Planning Committee. These requirements define standardized instrumentation which will be used for the two test phases of this program.

During the first phase or pre-installation period, the candidate test sites will be instrumented to record thermal and electrical load requirements as well as site environmental conditions. This data will be taken over a one year time period. In cases where the test facilities have not been constructed, the committee indicated that similar buildings can be instrumented to provide the required data. The McClellan test site, however, is operational and could be instrumented at any convenient time. The following general parameters will be recorded during the pre-installation period:

1) Outdoor temperature
2) Indoor temperature
3) Thermal energy consumption rate and its use temperature
4) Electrical consumption rate
5) Gas consumption

The instrumentation must also permit time referencing of the recorded data in order to accurately compare fuel cell electrical and thermal output with facility electrical and thermal power requirements. For instance, if facility electrical requirements are high when thermal requirements are low, full use of the fuel cell thermal energy may not be realized and overall energy utilization of the fuel cells could be lower than some other method of supplying energy to the facility. The converse could also be true if facility thermal requirements are high when electrical requirements are low.

The data shown in Table 1 for the McClellan facility will satisfy most of the pre-installation data recording requirements and this data is used in the report to evaluate fuel cell energy output against facility energy requirements.

For the second phase or field test program phase additional data acquisition requirements pertain to the performance of the fuel cells and are listed below:

1) KVA output of the fuel cell
2) Gas input to the unit
3) Available thermal energy
4) Thermal energy used and use temperature
5) Electrical input to the fuel cell
6) Various internal fuel cell measurements

Table 3 (excerpted from the "Fuel Cell Operational Feasibility Program Plan" subsection "Data Acquisition System" (Reference 5)) specifies these data points in more detail and gives the required sampling frequency. All program participants will utilize this data recording format and record the data on magnetic tape for submission to the Gas Research Institute (GRI). In turn, GRI will analyze the data and submit reports to the program participants.

The data acquisition equipment to be used by all program participants in the two test phases of the program are defined in Reference 5.

TABLE 3

INSTRUMENTATION INFORMATION PLAN

	INPUT SOURCE	OUTPUT DATA UNITS	NO. OUTPUT POINTS	TYPE OF OUTPUT	TOTAL MAX. OUTPUT POINTS	RECORD INTERVAL	REMARKS
1.	Building Gas Comsumption	Cubic Feet	1	Accumulated	1	Every 1/2 hour	-
2.	Thermal Energy Sources, Max. 3	BTU Temp Gal. Water	1 2 1	Accumulated Average Accumulated	3 6 3	Accumulated Each scan and record every 1/2 hour	Water flow and temps in and out are used to compute BTU
3.	Peak Electrical Demand	KW	1	Max Peak	1	Record maximum peak every 1/2 hour	Maximum peak occurring during all scans. Auto-reset every 1/2 hour
4.	Electrical Energy Consumption	KW	1 1	Average Low	1 1	Record every 1/2 hour	High recorded by input source 3
5.	Selected Electrical Energy Loads	KW	1 1	High Average	3 3	Record every 1/2 hour	Optional (up to 3 channel) as needed
6.	Ambient Temp	Fahrenheit	1	Average	1	Record every 1/2 hour	Shielded RTD
7.	Local Fuel Cell Temp if not Ambient	Fahrenheit	1	Average	1	Record every 1/2 hour	Only necessary if fuel cell is not located in ambient temp.
8.	Electrical Phase Amps	Amps AC	3 3 3	Low High Average	3 3 3	Accumulate each scan and record every 1/2 hour	Measure amps on each of 3 phases
9.	Electrical Phase Volts	Volts AC	3	Average	3	Accumulate each scan and record every 1/2 hour	Measure volts on each of the 3 phases

TABLE 3 (Concluded)

	INPUT SOURCE	OUTPUT DATA UNITS	NO. OUTPUT POINTS	TYPE OF OUTPUT	TOTAL MAX. OUTPUT POINTS	RECORD INTERVAL	REMARKS
10.	Unbalance	*Percent unbalance	1	High	1	Record every 1/2 hour	Measure maximum phase unbalance.
11.	Net Electrical Power, for Grid Connect Only	KW AC	1	Average	1	Record every 1/2 hour	
12.	Fuel Cell Thermal Output for Building Load, High Grade/ Low Grade	BTU Cubic Feet Temp	1 1 2	Accumulated Accumulated Average	2 2 4	Record each point every 1/2 hour	Measuring high grade and low grade outputs as appropriate
13.	Fuel Cell Gas Consumption	Cubic Feet	1	Accumulated	1	Record every 1/2 hour	
14.	Fuel Cell internal Data (2 Fuel Cells)			Accumulated Average High Low	36	Record every 1/2 hour	Channel specification to be provided by fuel cell manufacturer
15.	Site Identification	ID/Date/Time	1		1	Record every 1/2 hour	

TOTAL NUMBER OF OUTPUTS 84

* $(I_{max} - I_{avg})/I_{avg} \times 100$ = Imbalance

D66-30A

REFERENCE:
Specifications for Data Acquisition System, Fuel Cell Operational Feasibility Program Plan, Nov 30, 1979

SECTION VI

FUEL CELL MODIFICATIONS

Several potentially desirable fuel cell modifications were identified during the course of this study. Since these modifications could benefit fuel cell users, they are presented here for future consideration.

1. WATER PUMP MECHANICAL SHAFT SEALS

UTC personnel have indicated that fuel cell water pump mechanical shaft seals exhibited shorter life than anticipated during the prototype testing phase conducted in the South Windsor Facility. This problem could possibly be eliminated by using a water pump that does not require a shaft seal, such as the magnetic drive or canned motor pump.

The magnetic drive pump rotor is magnetically coupled to the electric motor driver, thus eliminating the necessity to extend a drive shaft through the pump housing. The submerged motor or canned motor pump places the electric motor rotor in contact with the pumped fluid and requires no drive shaft extension to be sealed. Both types of pumps are commercially available.

2. EXHAUST GAS FANS

Since the fuel cells are equipped with small combustion gas and air cooled heat exchanger fans (for energy conversion purposes), the facility exhaust ducting must impose no back pressure on the fuel cell exhaust system. As a result, installation of the cells at convenient locations within a facility may not be possible because of the necessity to use long runs of exhaust ducting or the inability to install large-diameter ducting to reduce the pressure drop. In these cases the user could benefit from larger fuel cell exhaust fans.

3. HIGH GRADE HEAT EXCHANGER SOLENOID OPERATED VALVE

The high-grade heat exchanger uses a two way (open/close) solenoid-operated valve to control the user water flow rate through the heat exchanger. This valve precludes the user from transferring excessive heat from the high grade heat exchanger which would shut down the fuel cell. Valve positions are either fully open or fully closed. When closed all user water flow is stopped, but in many fuel cell installation schemes this on/off water flow is undesirable. Two design changes are presented below which could eliminate this problem.

One possibility is to locate a solenoid operated three-way valve on the inlet side of the high grade-heat exchanger. When the existing fuel cell control system sends a signal to stop water flow through the heat exchanger, the valve would close the inlet but open a discharge port and allow the water to by-pass the high-grade heat exchanger and return to the user system. Water flow rates in the user system would remain constant, however, heat would not be added with the valve in the by-pass position.

The second approach would send a variable position signal to the three-way valve. This would allow varying amounts of water to flow through the high-grade heat exchanger depending on available excess heat while the remaining water would by-pass the heat exchanger and flow to the user system. This approach would also allow a constant water flow through the user system but would allow transfer of all available excess heat from the fuel cell.

4. LOW GRADE HEAT EXCHANGER

The mechanical design of the low grade heat exchanger limits outlet water temperatures to a maximum of 180^{o}F. A number of users would benefit from higher water temperatures. By replacing the existing heat exchanger with one designed to allow higher outlet water temperatures, a more versatile system would be available.

SECTION VII

EVALUATION OF INTEGRATION CONCEPTS

All of the fuel cell installation concepts described in Section IV can supplement the building electrical, heating, and cooling loads; however, operating costs, installation costs, building utility system reliability, and total energy consumption can vary considerable. Each of these integration concepts is evaluated below.

1. ELECTRICAL

Two installation concepts were presented in subsection 1 of Section IV for connecting fuel cell electrical output to the facility electrical system. One concept operated the fuel cells in parallel with the existing commercial power system, the other connected individual load buses to the fuel cells.

Operating costs associated with either of these concepts are identical since fuel consumption is based on electrical power output rather than the method used to connect the cells to the facility electrical load. In the Sacramento area the actual cost to produce electrical power with the fuel cell will exceed the cost of purchasing power from commercial sources. Commercial power in Northern California is obtained from hydroelectric power plants which can produce power at a much lower cost than hydrocarbon fueled plants. Based on 1979 utility rates (the latest available form the McClellen Facility), 1 kWH of fuel cell produced power would cost $.0415 while the same amount of commercial power can be purchased for $.0190. However, fuel cell by-product heat utilization would compensate for part of the rate differential.

Facility installation costs are significantly different for the two concepts. By connecting fuel cells in parallel with commercial power, sophisticated impedence matching circuits, auto-transfer switches, paralleling equipment, and current sensors will be required. These components must be specifically designed for the system as opposed to standard components which can be used in the direct-load-connect option. The high procurement and installation costs for these special components would not be justified.

Utility system reliability would not be enhanced with parallel connected system. Since the facility loads are greater than the 80 kW produced by the fuel cells, any loss of commercial power would overload the fuel cells. In addition the sophisticated electrical components required for this mode of operation would increase the likelihood of equipment failure.

The direct-load-connection concept, on the other hand, would not overload the fuel cells during commercial power failure. This method of using fuel cell power could also allow operation of the entire building electrical system during commercial power failures (emergency generator plus fuel cell power can carry the full building electrical load). An added advantage is that fuel cell failures would not disrupt facility operation because automatic transfer switches would switch to either commercial power or emergency generator power after cell failı The direct connection method of operation would allow maintenance of the fuel cells without affecting normal building operation.

The fuel cells would be continuously operated at maximum electrical output with either connection arrangement since the minimum required building electrical load always exceeds the combined output of two 40-kW fuel cells.

2. HEATING

Three installation concepts for utilizing fuel cell by-product heat were described in subsection 2 of Section IV. Two concepts supply heat directly to the existing hot water return system while the third method requires installation of a separate hot water system and the installation of heat exchangers in the air distribution system.

Operating costs (fuel costs) for all three of these concepts would be identical since the fuel cells would be operated at maximum electrical output. However, total energy utilization and consequently the amount of additional fuel required to satisfy the facility thermal needs would be different.

With the two return-water heating concepts, between 80,000 and 93,000 BTU/HR could be supplied to the building heating system (reference Section IV.2.1). On the other hand, 175,000 BTU/HR (125,000 BTU/HR from

TABLE 4

FACILITY POWER REQUIREMENTS USING 2-40 KW FUEL CELLS
(CONSTANT ELECTRICAL OUTPUT, 80 KW)

MONTH -1979-	INPUT FOR FUEL CELLS (THERMS)	INPUT FOR FUEL CELLS - DOLLARS	ADDITIONAL FUEL REQD (THERMS)		ADDITIONAL FUEL COST (DOLLARS)		ADDITIONAL ELECTRICITY REQD (KWH)	ADDITIONAL ELECTRICITY COST (DOLLARS)	TOTAL COST (DOLLARS)		
			*	**	*	**			+	*	**
JAN	5714	2468	1628	0	703	0	3000	57	2550	3228	2525
FEB	5161	2230	1883	322	816	141	14760	280	2713	3326	2651
MAR	5714	2468	300	0	130	0	1680	32	1951	2630	2500
APR	5530	2389	290	0	125	0	3240	62	1919	2576	2451
MAY	5714	2468	-	0	0	0	2880	55	1749	2523	2523
JUN	5530	2389	-	0	0	0	14520	276	1797	2665	2665
JUL	5714	2468	-	0	0	0	8040	153	1522	2621	2631
AUG	5714	2468	-	0	0	0	5400	103	1526	2571	2571
SEP	5530	2389	-	0	0	0	15240	290	1830	2679	2679
OCT	5714	2468	-	0	0	0	4440	84	1876	2553	2553
								TOTALS	19,433	27,372	25,739

\+ Total utility costs - present system
* Assumes 80,000 BTU/hr recoverable by-product heat from each fuel cell
** Assumes 75,000 BTU/hr recoverable by-product heat from each fuel cell

the low-grade heat exchanger and 50,000 BTU/HR from the high-grade heat exchanger, reference Section IV.2.2) could be supplied by directly heating the building return air in the duct-mounted heat exchangers. Table 5 shows utility costs associated with each installation concept.

Installation costs for the new duct-mounted heat exchangers would be prohibitive since the assumed heat transfer rate requires large heat transfer surface areas and extensive air duct modifications. The large heat exchangers would be required to heat the return air with the low temperature hot water produced by the fuel cell. Installation costs would be small for the two return water heating concepts since only minor piping modifications are required. Heating system reliability would not be affected by any of these concepts since these systems would operate in parallel with the existing heating system.

3. COOLING

Two methods were discussed in subsection 3 of Section IV to augment the building's cooling system by using fuel cell by-product heat. One method used by-product heat to drive an absorption chiller and the other used by-product heat to drive a vapor-jet refrigeration system. Facility installation costs for either of these two systems would be essentially the same. The cost of the vapor-jet refrigeration machine, however, cannot be determined since the device is not commercially available at this time. Either system would be relatively simple to integrate into the HVAC system since a minimum of facility changes would be required. The primary advantage of using by-product heat for building cooling is to offset fuel cell operating costs. Since the building heating load is low during the summer months, all of the thermal output of the cells cannot be used to augment the building hot water system and the by-product heat would have to be rejected to the atmosphere through the air-cooled heat exchangers.

The absorption chiller and vapor-jet systems require essentially the same amount of fuel cell by-product heat and will produce approximately six tons of refrigeration with two operating fuel cells. Operating costs for either system, therefore, will be approximately the same. Based on 0.746 kWH/TON of cooling and 1979 utility rates, approximately $61.25 per month of purchased electrical power could be saved by using by-product heat to augment the cooling system load.

Building cooling system reliability will not be reduced with either approach since these systems would be operated in parallel with the existing cooling system.

TABLE 5

TOTAL UTILITY COST COMPARISON

Month in 1979	Total Utility Costs (Dollars)				
	(1)	(2)	(3)	(4)	(5)
Jan	2550	3228	2525	3485	3228
Feb	2713	3326	2651	3552	3325
Mar	1951	2630	2500	2911	2630
Apr	1919	2576	2451	2818	2576
May	1749	2523	2523	2687	2329
Jun	1797	2665	2665	2697	2238
Jul	1522	2621	2621	2557	2269
Aug	1526	2571	2571	2507	2194
Sep	1830	2679	2679	2729	2290
Oct	1876	2552	2552	2804	2552
Total	19,433	27,372	25,739	28,746	25,632

(1) Present facility (from Table 1)

(2) Assumes 80,000 BTU/hr recovered by-product heat from each fuel cell (Constant maximum electrical output).

(3) Assumes 175,000 BTU/hr recovered by-product heat from each fuel cell (heat exchangers in return-air ducts and constant maximum electrical output).

(4) Assumes high-grade heat to absorption chillers, 43,000 BTU/hr low-grade heat to return hot water and constant maximum electrical output.

(5) Assumes thermal load following mode of operation.

SECTION VIII

IMPLEMENTING ORGANIZATIONS (SELECTION)

If the McClellan Facility is selected as the fuel cell demonstration site, two additional tasks must be accomplished. Detailed installation specifications must be developed for the selected installation scheme and a construction organization must be chosen. Either or both of these tasks can be accomplished by the McClellan Civil Engineering unit or by an outside contractor.

The advantages/disadvantages of these two options are discussed below. The base civil engineering organization is already on site and familiar with the facility. If the civil engineering organization is chosen to install the fuel cells, the level of detail required in the installation specifications could be reduced since a formal contract would not be required. Coordination of construction activities between the facility using organization and the base civil engineering organization would be simpler than between the user and an outside contractor. Base civil engineering personnel will be in a better position to operate and maintain the fuel cells during the test program, if that organization prepares the installation specifications and installs the fuel cells.

If an outside contractor is involved in any phase of the project, additional time will be required to develop a higher level of detail in the installation specifications. On the other hand, these detailed specifications would provide a better record of the facility modifications. In general, use of an outside contractor would increase the cost of these two phases of the project.

SECTION IX

CONCLUSIONS/RECOMMENDATIONS

1. SITE SUITABILITY

The McClellan AFB RAPCON Facility is judged to be an acceptable site to use in the National Fuel Cell Operational Feasibility Program. This judgment is based on the following considerations:

a) Fuel cell thermal and electrical output can be integrated into the existing facility utility system without reducing the reliability of the facility. This is accomplished by operating the fuel cells in parallel with the existing utility system.

b) The facility can utilize the entire electrical output and most of the by-product heat produced by the two 40-kW fuel cells.

c) The required modifications are relatively simple and inexpensive.

d) The moderate climate will permit outdoor installation of the fuel cells.

e) There are no access or space limitations associated with this facility.

f) Skilled manpower is available to install and operate the cells.

2. OTHER CONSIDERATIONS

Although facility operating (fuel) costs will be slightly increased if the fuel cells are installed in the RAPCON facility, this disadvantage is considered small when weighed against the fuel cell field test objectives and the parameters listed in subsection 1 of Section IX.

3. RECOMMENDED INSTALLATION CONCEPT

In Section IV basic installation concepts were presented which use fuel cell by-product heat in the building heating and cooling systems as well as supply electrical power to the facility. Each installation concept offered certain advantages; however, overall test program objective would be better satisfied by employing the installation schemes described in Sections IV.1.2 and IV.2.1. These are:

a) Connect the electrical output of the fuel cells to individual load buses through automatic transfer switches. Bus selections would be based on using the full 40-kW output of each fuel cell and the fuel cells would not be operated in parallel with each other or any other power source.

b) Connect the fuel cell high-grade and low-grade heat exchangers to the existing facility hot water return line as shown in Figure 16b.

c) Locate the fuel cells on a small concrete pad outside of the east wall of the building.

These recommendations are based on achieving the fuel cell field test objectives at minimum program cost, simplifying the installation scheme to reduce the risk of non-fuel-cell related equipment failure, and minimizing the building modification effort.

Use of fuel cell by-product heat to cool the building is not recommended at this time since additional equipment and capital costs would be added to the project without producing any useful fuel cell performance data.

4. PROJECT IMPLEMENTATION

Development of the detailed installation specifications and performance of the field construction activities should be assigned to the McClellan Civil Engineering Unit. It is felt that these functions can be accomplished in the most expeditious manner and at a lower cost by using base civil engineering versus using an outside civilian contractor. This assumption, however, is dependent on the workload and unit manning at the time the fuel cell work in initiated.

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